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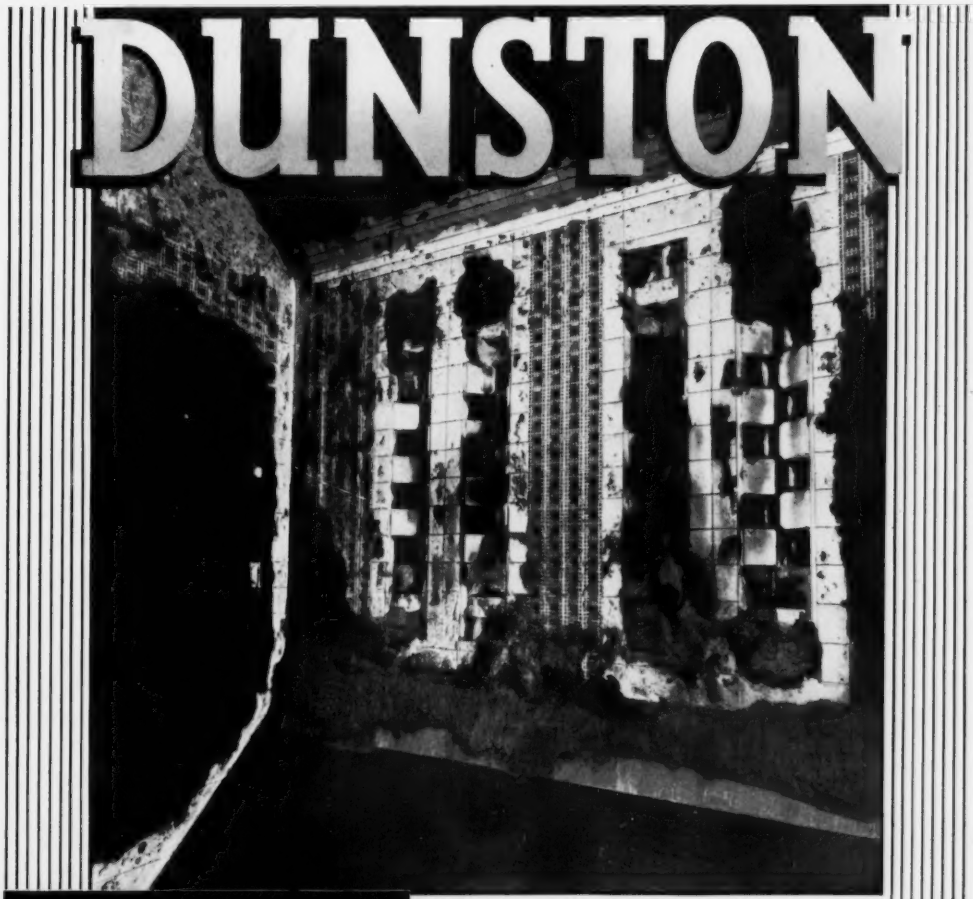

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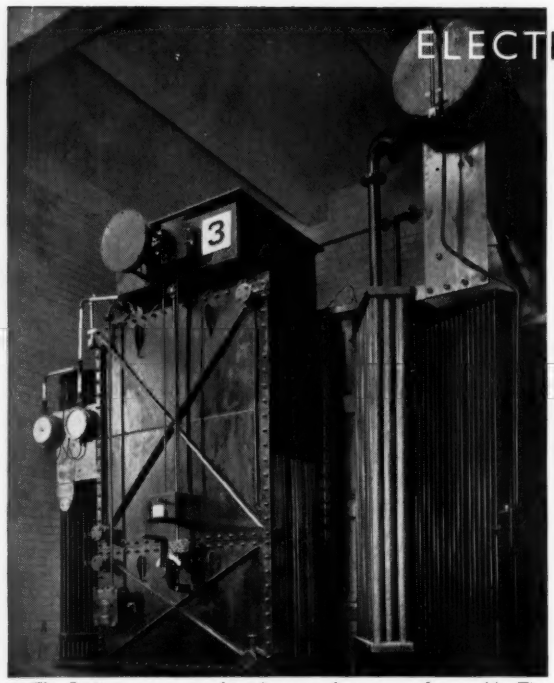

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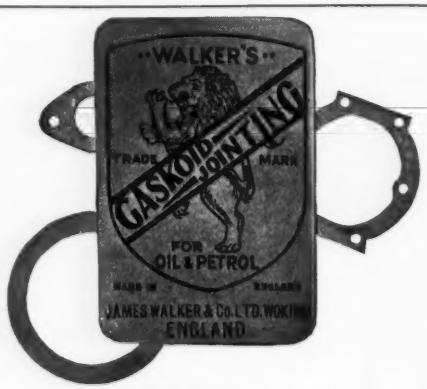

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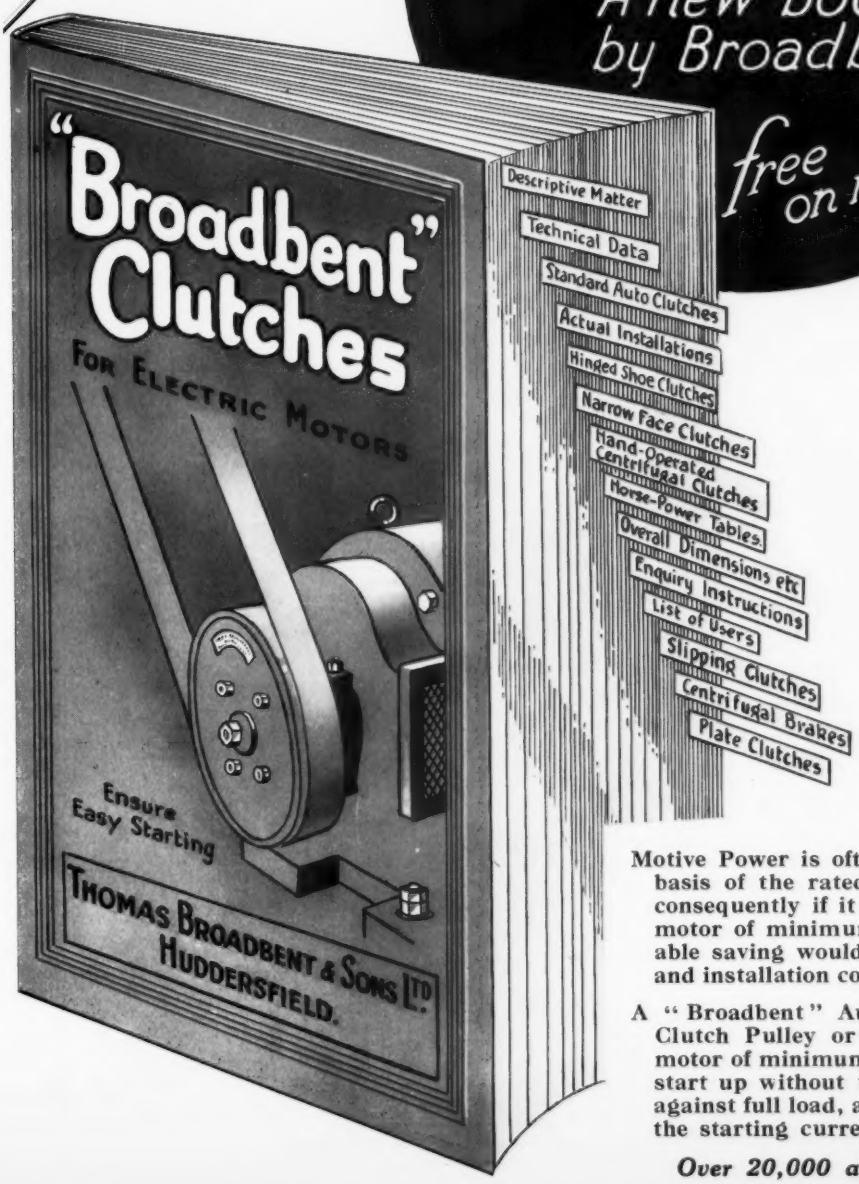

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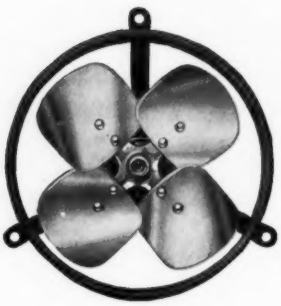

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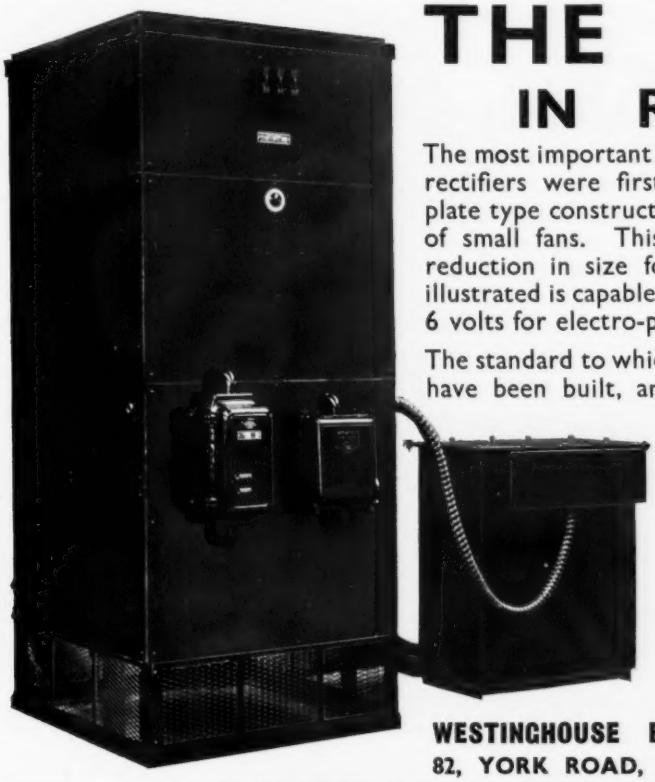

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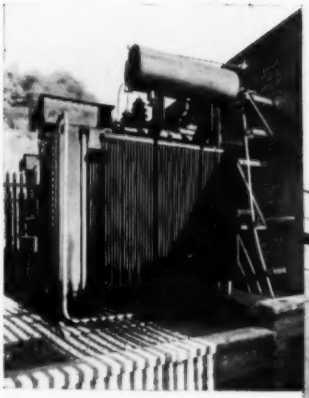

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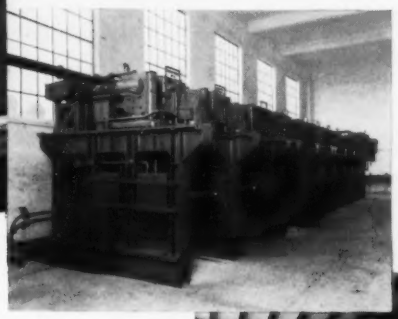

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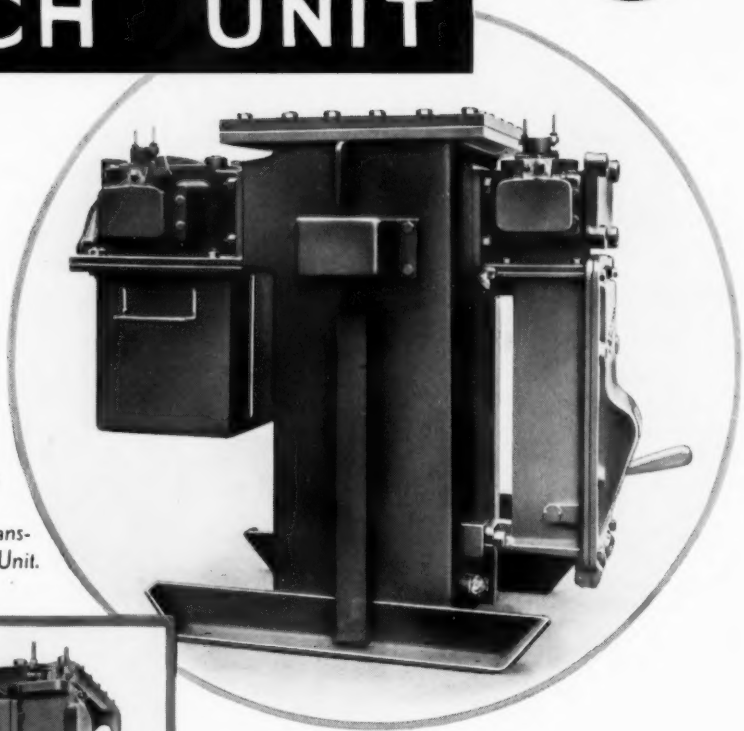
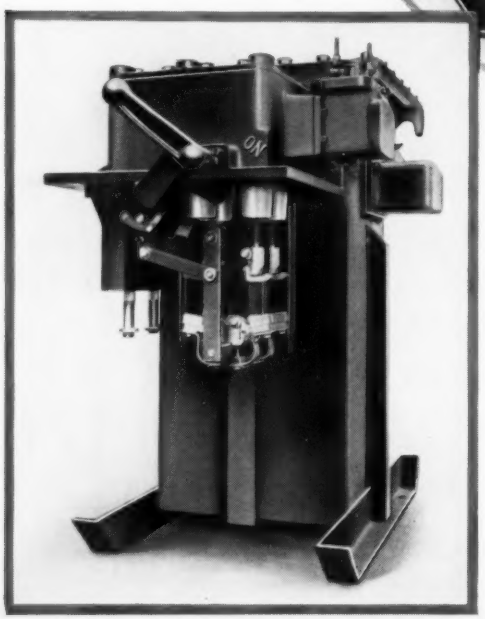


The illustrations show an "English Electric" Combined Flameproof Transformer and Switch Unit.



View of Unit with Tank of H.V. Switch removed.

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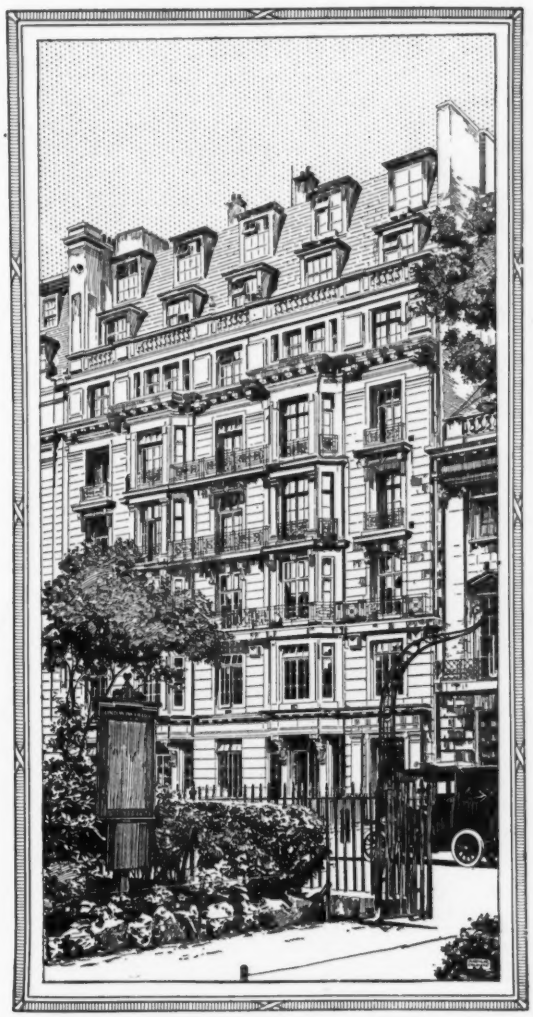

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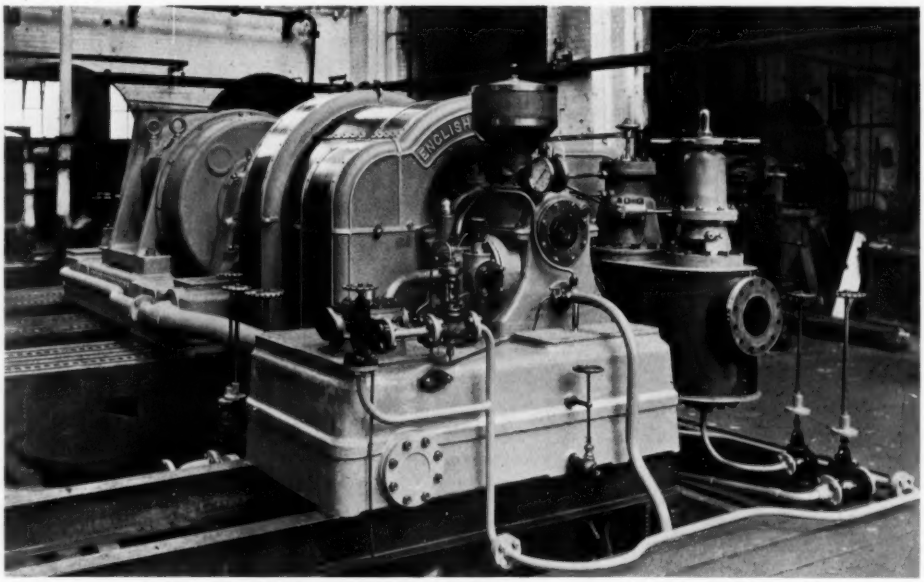
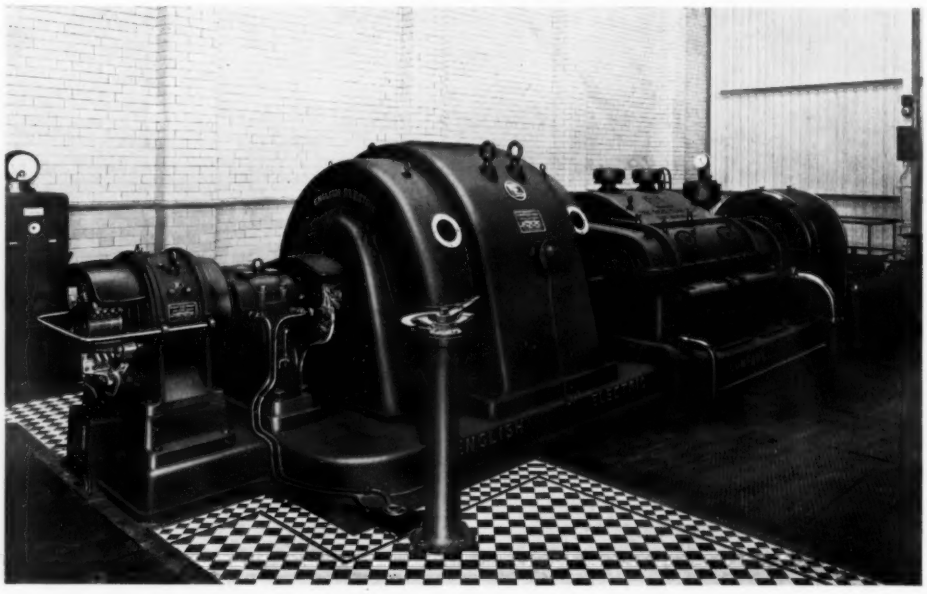


675 kw. Back-Pressure Turbo-Alternator set for Dhrangadhra State Chemical Works.



2,500 kw. Back-Pressure Turbine for operating at a steam pressure of 1,100 lb. per sq. in. at the Valley Road Power Station, Bradford.

The English Electric Journal

Vol. VII. No. 5 · JULY/AUGUST, 1935 · One Shilling.

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All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, THE ENGLISH ELECTRIC COMPANY LIMITED, STAFFORD.

EDITORIAL.

Many of our readers have, no doubt, read the announcements which have appeared in the press concerning the important contract awarded to the Company by the Southern Railway. It is not our intention here to refer to the details of this contract, but for the benefit of those who have not seen these announcements we may state that the contract covers the supply of electric train equipment, including motors and control gear, for the Southern Railway's requirements for the next ten years. We believe this contract to be the largest ever placed for electric equipment in this country by a British railway.

Many industries require large quantities of low-pressure steam for their various processes, and it has long been recognised as uneconomical to raise such steam by means of separate boilers. In many cases a back-pressure turbine is the most suitable means of obtaining the low-pressure steam required, and in the first article in this issue Mr. J. P. Chittenden deals with this type of turbine and its various applications.

The second article is devoted to a description of the house service watt-hourmeters recently put on the market by the Company. These meters embody design and manufacturing experience extending over a period of thirty years.

A study of the various curves in Mr. G. Tilstone's article shows the advantage possessed by the fully compensated meter as compared with the uncompensated or partially compensated meter over a wide range of loads.

For installation in localities where the provision of earthing facilities is difficult, an all-insulated meter, housed in a strong moulded bakelite base and cover has been developed.

The meters are manufactured at the Company's Stafford works in a self-contained factory, equipped with the most up-to-date tools and plant for producing a high-class precision instrument. It is proposed to describe this factory, and also other types of meters, in a later number of this Journal.

The use of electric arc welding has, in recent years, increased considerably, and in the last article in this issue Mr. T. A. Long deals with the many advantages to be obtained from the use of electric welding and describes, in particular, the alternating current arc welding equipment recently developed by the Company.

THE DIESEL-ELECTRIC PADDLE VESSEL TALISMAN.

This vessel has recently been put into service on the Clyde by the London & North Eastern Railway Co. The hull was built by Messrs. A. & J. Inglis, Ltd. the propulsion machinery consisting of four 400 H.P. Diesel Engines and Generators, the main propulsion motor, control gear and auxiliary machinery was supplied and installed by The English Electric Company.

The Back Pressure Turbine and its Application.

By J. P. CHITTENDEN, A.M.I.E.E., M.I.Mech.E.
Engineer and Manager, Turbine Department.

Introduction.

Recent years have witnessed considerable developments of the steam turbine along certain lines to meet the specialised demands of particular industries, such as the textile and its allied industries — dyeing, carpet making, leather working, paper making, chemical works and the like—which require not only electrical power but also large quantities of low-pressure steam for their various processes, and again for the heating of buildings.

It has long been recognised as uneconomical to generate steam for process work in a separate system, and the practice of producing steam at a high initial pressure and expanding this steam in a turbine to generate electrical power, before passing to the process work, is now well established.

When the relative variations between steam and electrical load are wide, pass-out condensing type turbines are employed, in which the necessary quantity of steam for process or heating purposes is extracted from the turbine after the high-pressure portion, and the remainder passes through the low-pressure portion of the turbine, thus doing further useful work before being exhausted into the condenser. In such a turbine, large variations in steam and electrical load can be met in an efficient and economical manner by controlling the amount of steam passing to the low-pressure end of the turbine. This control can be obtained without any variation in the speed by special governor gear as used by the English Electric Company.*

Back-pressure Turbines for Industrial Purposes.

In many industries, such as those already mentioned, there are cases where the demands for steam and electrical power are in practically constant proportions, and for such conditions the back-pressure type of turbine is in many ways more suitable.

The back-pressure turbine is of simpler construction since all the steam entering the turbine is exhausted into the heating or process mains. The low-pressure portion of the turbine and condenser being dispensed with, results in a less expensive plant and layout, and at the same time a higher thermal efficiency is obtained, due to the saving in windage and idle steam losses, which occur in the low-pressure end of a pass-out condensing type turbine under certain conditions of working.

The relation between the quantity of steam exhausted from the turbine and the electrical output is, of course, an inherent characteristic of the machine, but provision for slight variations from proportionality between steam and load requirements can be made in a variety of ways depending upon the particular circumstances, and without appreciably affecting the overall thermal efficiency of the plant.

In the case where a separate electric supply is available, the whole of the steam required for process is passed through the turbine and any excess electrical power generated is fed into the external system. Conversely, if the steam passing through the turbine is insufficient to provide the requisite electric load, then power can be drawn from the line.

A typical example of turbines built by the English Electric Company to meet these conditions of operation is shown in Fig. 1, which illustrates two 10,000 kW. 3,000 r.p.m. back-pressure machines designed to work at an initial steam pressure of 565 lbs./sq. in. absolute, 725° F. total temperature, exhausting into the process main at a pressure of 55 lbs./sq. in. absolute, with provision for raising the pressure, if desired, to 70 lbs./sq. in. A special oil-operated control of "English Electric" design

* *See paper before the Institution of Mechanical Engineers, Bradford, October, 1924 (Chittenden and Burge) on "Steam Extraction or Pass-out Steam Turbines."*

is fitted to ensure a constant back pressure under all conditions of working.*

These turbines were supplied to the order of the State Electricity Commission of Victoria for a briquetting factory at Yallourn, where the primary requirements are for constant pressure process steam used in drying the raw coal.

In cases where the back-pressure turbo-generator is the only source of electric supply and the proportion of process steam to electrical output is reasonably constant, any slight variation can be provided for by exhausting a portion of the steam to atmosphere when the electrical load is greater than steam demand, and, on the other hand, by adding high-pressure steam through a suitable reducing valve to make up any deficiency in low-pressure steam for process work.

This, however, as will readily be appreciated, shows no economic advantages if taken beyond certain limits, and the case then would be better met by the installation of a condensing turbine of the pass-out type.

The upper illustration of the frontispiece shows an "English Electric" back-pressure turbine designed to operate on the principles mentioned above for use in a chemical works in North-West India.† The machine is of the simple impulse type having 9 stages of about 30 in. diameter, designed to give an economical output of 675 kW. at a speed of 3,000 r.p.m. and an overload capacity of 1,125 kW. The initial pressure is 240 lbs./sq. in. gauge with a superheat of 140° F., the turbine exhausting under normal conditions into a process main at a back pressure of 30 lbs./sq. in. gauge. It is fitted with reducing, atmospheric relief and change-over valves combined in one unit as shown in Fig. 2; these valves, together with the automatic control, were designed and built by the English Electric Company.

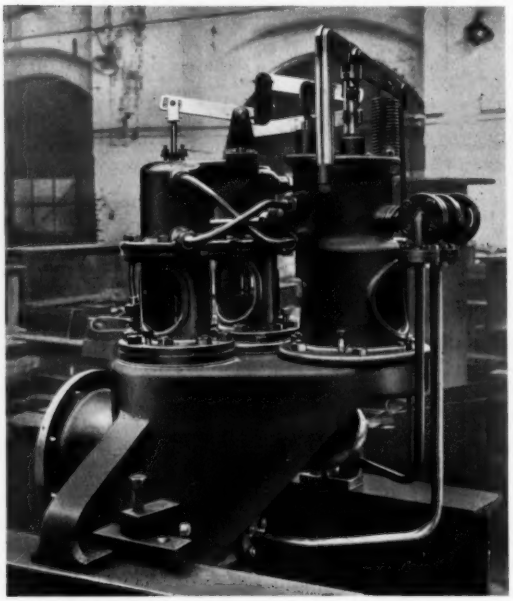


Fig. 2. Combined Reducing, Atmospheric Relief, and Change-over Valves.

* *See* "*Engineering*," *December 5th*, 1930.

† *See* "*Engineer*," *January 14th*, 1927.

Fig. 1. Two 10,000 kW. Back-Pressure Turbo-Alternator Sets in a Briquetting Factory.

Back-pressure Turbines Superposed on Existing Plant.

A further important application of the back-pressure turbine is the superposition of such on existing turbo-generator plant, by which means, with the addition of boilers working at a higher initial pressure, the thermal efficiency of the station can be greatly improved.

In such a case the high-pressure steam, after passing through the back-pressure turbine, exhausts into the steam main of the existing turbines at their designed pressure.

The lower illustration of the frontispiece shows an "English Electric" back-pressure turbine installed in a large generating station in the north of England.* This station was originally designed for a normal working pressure of 200 lbs./sq. in., and subsequent extensions were carried out on the same basis, later the need arose for still further extensions coupled with the increasingly important necessity for an improved overall thermal efficiency, which, it was appreciated, could only be attained by the use of higher initial steam conditions. To meet these requirements and at the same time utilize the existing plant, the 2,500 kW. 6,000 r.p.m. back-pressure turbine illustrated was installed in conjunction with a boiler operating at 1,100 lbs./sq. in., the steam temperature being 800° F.

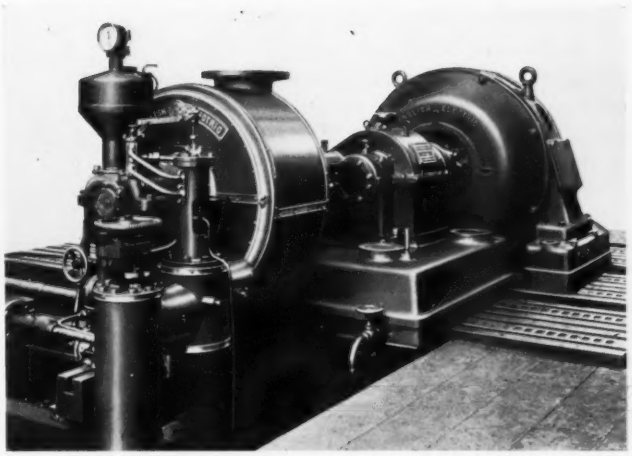


Fig. 3. 250 kW. 600 R.P.M. Geared Back-pressure Set for Athens Power Station.

The turbine exhausts at about 205 lbs./sq. in., 525° F. total temperature, and the steam is passed through a reheater integral with the high-pressure boiler, where it is raised to a total temperature of 700° F., and thence passed to the main steam range of the station supplying the existing medium pressure turbines, where it generates a further 6,500 to 7,000 kW. before finally being rejected to the condenser.

This plant was designed and constructed to the instruction of Mr. Thos. Roles, M.I.E.E., City Electrical Engineer, Bradford, the English Electric Company being Main Contractors for the whole equipment.

Back-pressure Turbines for Auxiliary Services.

When for any reason the main generating plant in a station is closed down, and the station is isolated from any external source of electric supply, it becomes necessary to install emergency plant to provide power for lighting and for starting up the main turbine auxiliaries before the main sets can be put into commission. In such circumstances of infrequent operation where initial cost takes priority over running cost, the back-pressure turbine, discharging to atmosphere, is the obvious solution, and for emergency service it has the advantage of being independent of condensing plant, which gives added reliability by virtue of this reduction of components to the elementary necessities.

An example of this is shown in Fig. 3, which illustratres a 250 kW. 6,000 r.p.m. geared back-pressure turbine and generator erected on the test bed at the Company's Rugby Works. This unit was supplied as a house set to provide lighting and incidental electric power for auxiliaries in conjunction with the main generating plant for a large mid-European Power Station, and is designed to operate at the same steam conditions as the main sets, namely, 300 lbs./sq. in. at the turbine stop valve, total temperature 700° F. The turbine exhausts at 16 lbs. per sq. in. absolute, and the exhaust steam can be used for feed heating, or exhausted to atmosphere as may be desired.

A further development of the back-pressure turbine for emergency power station auxiliary service is the quick-starting set which is designed and arranged so that it may be put into commission immediately either by hand operation,

* *See* "*Engineering*," *January 26th*, 1934.

by remote push-button control from the control room switchboard, or automatically on failure of the electric supply to the main turbine auxiliaries.

In this case also the turbine is of the back-pressure type exhausting to atmosphere, and is of particularly robust construction so that it can be run up to speed in less than a minute, thus giving a supply of power and lighting for immediate use in the boiler house and turbine room.

The operating gear of such a turbine is of the simplest possible nature ; for hand control at the turbine, the operation of one valve sets the auxiliary steam-driven oil pump in motion, and with the attainment of an adequate working oil pressure the steam control valves automatically admit steam to the turbine. On reaching its designed speed the main governor takes control and the machine is then ready to take load up to its maximum rated output. Remote operation is effected by means of a single push-button and automatic operation following on the failure of the main electric supply, of course, needs no manual intervention.

Fig. 4 illustrates a 300 kW. 3,000 r.p.m. quick-starting set erected on the test bed at the Company's Rugby Works for Hayle Power Station, Cornwall. All three alternative methods of starting mentioned above are provided on this machine. The electrical relay circuits are battery-operated.

The set is of the simplest construction, comprising a single overhung Curtis wheel of 30 in. diameter mounted on an extension of the generator shaft, and is designed for a normal working pressure of 250 lbs./sq. in., total temperature 730° F., exhausting to atmosphere. In order to meet further contingencies such as may arise due to the failure of boiler auxiliaries the turbine blading is designed to have an ample capacity to pull full load even at very considerably reduced steam pressure.

Yet another field of application for the back-pressure turbine is that of marine auxiliary service. Fig. 5 shows one of two 400 kW. 6,000 r.p.m. geared back-pressure turbines built for this service. These machines are designed for a working pressure of 400 lbs./sq. in., total temperature 700° F., and are arranged to exhaust either to the main condensers or, as back-pressure machines, to atmosphere in the event of the main condensers being out of service. They are of the impulse type having one Curtis wheel followed by one simple impulse stage.

Construction.

The construction of English Electric back-pressure steam turbines follows generally that of the Company's high-pressure turbine practice in which field it has had considerable experience, including the first experimental example of the Benson boiler and its accompanying turbine, which was operated with steam generated at 3,200 lbs. per sq. in., reduced to a pressure of 1,420 lbs. per sq. in. at 900° F., total temperature prior to entering the turbine.*

The outstanding features of construction include a rotor machined from a solid forging, thus ensuring maximum rigidity, low working stresses, and giving

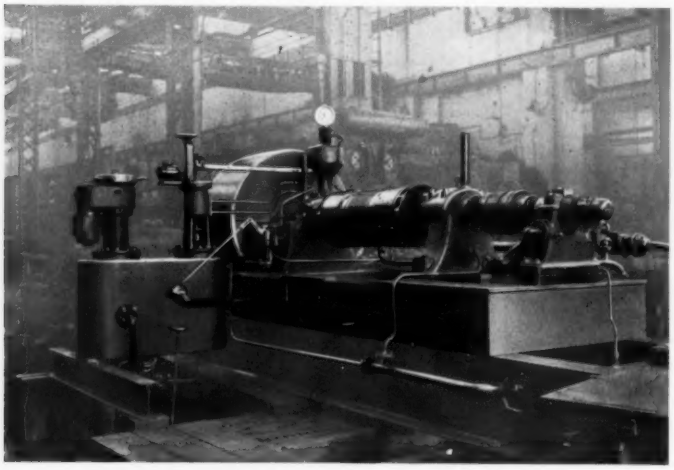


Fig. 4. 300 kW. 3,000 R.P.M. Quick-starting Back-pressure turbine, on test at the Company's Rugby Works.

* *See paper before the Institution of Electrical Engineers in London, November 3rd, 1927 (Law and Chittenden) on "Higher Steam Pressures and their Application to the Steam Turbine."*

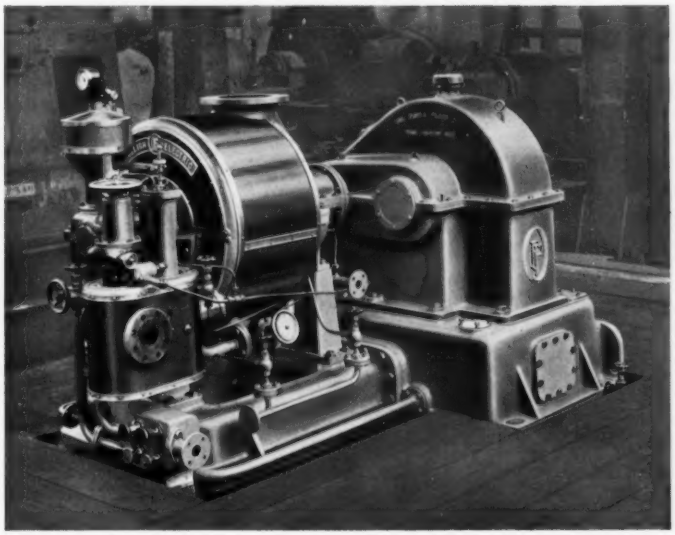


Fig. 5. 400 kW. 6,000 R.P.M. Geared Back-pressure Turbine for ship auxiliaries.

a critical speed well removed from the normal running speed. The employment of a solid rotor having discs integral with the shaft also leads to reduced diaphragm gland losses in as much that the gland diameter is smaller than for separately mounted discs.

Built-up nozzles and diaphragms are employed throughout the high-pressure end of the turbine, which enables accurate machining and finishing of all faces of the steam passages to be carried out, with the consequent assurance of a highly efficient steam flow.

The rotor blading, to meet the exacting conditions of high pressures and temperatures, is of special alloy steel accurately machined from solid bar.

Efficiency of Back-pressure Turbines.

The efficiency of back-pressure turbines is inherently of a very high order due to the fact that in most cases the steam is in the superheated state throughout all stages of the turbine. As a consequence, there is no loss due to the braking action of wet steam such as occurs in the low-pressure end of condensing turbines. Furthermore, since the ratio of steam quantity to output is relatively large, steam losses at the glands, etc., are a smaller percentage of the total losses in the turbine.

As a matter of general interest, Fig. 6 shows the approximate steam consumption in lbs. per kW.-hr. of back-pressure turbines of moderately small output designed for various initial steam conditions and exhaust pressure, and it should be added that for larger machines these figures can be improved upon by 10 per cent. or more, depending upon size, design and conditions of working.

Among the orders recently received by the English Electric Company for back-pressure

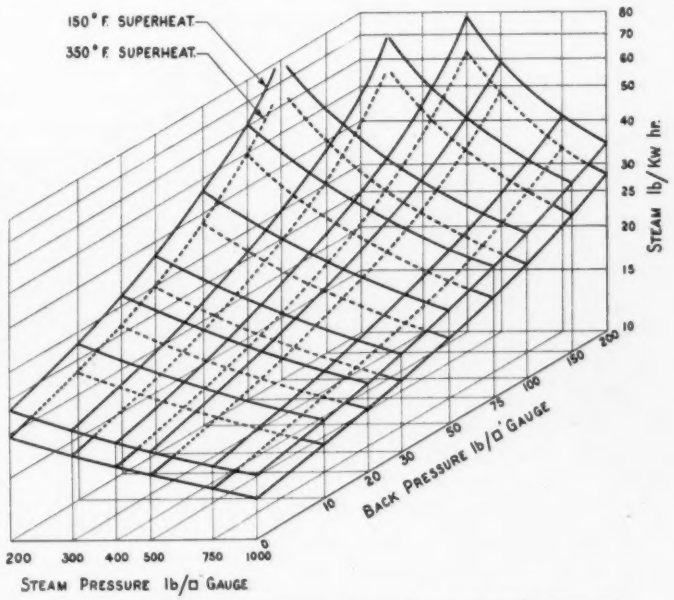


Fig. 6. Steam consumption curves for various steam inlet pressures and temperatures exhausting at different back-pressures.

machines it may be of interest to note the following :—

One 1,600 kW. 6,000 r.p.m. geared back-pressure turbo-generator set for the British Aluminium Company. This machine is for their Burntisland Works, and will be run at practically constant load and constant quantity of exhaust steam, any balance of power being obtained from other sources of supply. The conditions of working are : 170 lbs. per sq. in., 500° F. total temperature at the turbine stop valve, exhausting at a back pressure of 25.7 lbs. per sq. in. absolute.

One 728 kW. 5,000 r.p.m. geared back-pressure turbo-generator set for Messrs. MacRobertson's factory, Australia, for use in the manufacture of sweets and confectionery. The steam conditions are : 640 lbs. per sq. in., 645° F. total temperature, back pressure 140 lbs. per sq. in. absolute.

One 2,000 kW. 6,000 r.p.m. geared back-pressure turbo-generator set for Slough Trading Estates, Ltd., the initial steam conditions being : 600 lbs. per sq. in., 700° F. total temperature. This machine is of the superposed type exhausting into existing turbines at a pressure of 215 lbs. per sq. in. absolute, one of the existing machines being an " English Electric " multi-stage, single-cylinder turbo-generator of 7,500 kW. maximum continuous output, which turbine was described in the English Electric Journal, Vol. VI, No. 4, January-March, 1933.

Modern House Service Watthourmeters.

By G. Tilstone, A.M.I.E.E.

The importance of Watthourmeter performance to the Power Supply Company needs no special emphasis. Whatever system of tariffs is employed the accurate registration of the meter is of vital importance whether it forms the basis of charge for Bulk Exchanges of thousands of kilowatts or merely meters the domestic supply.

It will be readily appreciated that, apart from any system of standing charges, any metering error directly affects the total power sales revenue from that particular load by the same amount. Any temporary slight drop in generation or distribution efficiency merely affects a comparatively smaller portion of the production costs by the percentage concerned.

Concurrently with the attainment of higher efficiency in the production and distribution costs, the demand for greater accuracy in the metering of the energy at the point of consumption has resulted in the gradual development of meters of improved performance and life.

Thus from the point of view of initial characteristics and accurate running over long periods the Watthourmeter must be ranked as an electrical instrument of precision.

Extensive research has contributed to the manufacture of quantity produced meters of commendable performance and, although certain features are possibly capable of improvement, it must be admitted that at current prices the Watthourmeter represents one of the most highly developed and finished pieces of apparatus produced by the electrical industry.

The House Service Meter produced by the English Electric Company embodies design and manufacturing experience extending over thirty years.

Each individual component has been evolved as a result of constant research in material and manufacturing processes over many years, while the complete instrument presents a well finished product of easily assembled precision-machined units.

Although the material costs per meter are appreciably higher than the average, modern methods of production employing the latest developments in machine tools and testing apparatus enable the meter to be produced at a competitive price.

Considered as an assessor of revenue, the costs of the features embodied will be seen to be well warranted.

Required Performance.

The required performance of electricity meters is laid down in B.S.S. No. 37 Specification for Electricity Meters 1930 the sections of greatest practical importance being the accuracy over a certain range of load at unity and 0.5 power factor, starting current and change in performance with change in voltage.

Sustained accuracy over a period of three to five years before overhauling is of vital importance both from the point of view of avoiding loss of revenue and also in keeping maintenance costs to a minimum.

Load Curve Requirements.

In Fig. 1 the limits of errors specified by B.S.S. No. 37 are shown graphically by figures DEFG and HJKL. It will be noticed that the limits of error are specified up to a load of 125 per cent. of normal current, at which load the maximum error in registration permitted is ± 2 per cent. Rectangle PQRS is the figure in which the Load Curve A of the English Electric Meter Type UW falls.

It will be seen that the band of error PS is only a fraction of the permitted band DL, while the range of load represented by PQ represents 300 per cent. of normal load as against 125 per cent. for the permitted error of ± 2 per cent.

Value of Overload Capacity.

Due largely to the rapidly increasing installation of electrical domestic appliances, a great deal of attention is being paid to the performance of meters on overloads. It is necessary, therefore, to examine very carefully the commercial and practical advantages accruing from the use of such meters, and also to consider the effect of sustained overloads on the life of the meter.

For many years it has been the practice of meter manufacturers to give load performance figures up to 200 per cent. of normal load, and, although the load capacity of 200 per cent. normal is accepted by meter buyers as a matter of course, there is no doubt that the 100 per cent. margin has been regarded as necessary to cope only with exceptional circumstances.

The objections raised to running meters on sustained overloads can be broadly classified under three headings :—

1. Inaccuracy of Registration on Overloads.
2. Shortened life of meters.
3. Increased noise.

Dealing with the first objection, this has been based on the fact that the load curve of a meter which is not specially compensated for overload, droops very badly from 150 per cent. of normal load upwards, and that self-heating errors are introduced owing to the high temperature rise of the windings.

Referring to Fig. 1, load curves up to 300 per cent. normal are shown for three different makes of meters. It will be seen that the curve of the fully compensated meter droops only 0.6 per cent. at three times full load.

For the purpose of illustrating more clearly the advantages of a fully compensated meter, the curves in Fig. 1(a) are compiled from the characteristic curves in Fig. 1. Fig. 1(a) shows the actual watts unregistered at various loads up to 300 per cent. and brings into prominence the fact that even at the accepted overload capacity of 200 per cent. :—

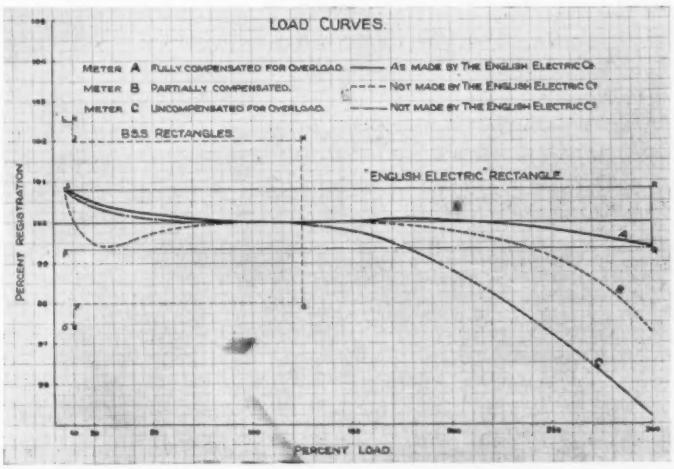

LOAD CURVES.
METER A FULLY COMPENSATED FOR OVERLOAD. — AS MADE BY THE ENGLISH ELECTRIC Co.
METER B PARTIALLY COMPENSATED. - - - NOT MADE BY THE ENGLISH ELECTRIC Co.
METER C UNCOMPENSATED FOR OVERLOAD. — NOT MADE BY THE ENGLISH ELECTRIC Co.
B.S.S. RECTANGLES.
"ENGLISH ELECTRIC" RECTANGLE.
PERCENT REGISTRATION
PERCENT LOAD.

Fig. 1. Load Curves for three different makes of Meter.

Meter C fails to register 56 watts x time.

Meter B fails to register 10 watts x time.

Meter A registers the whole energy.

It should be noted that at 300 per cent. of normal load, the value of the fully compensated meter, curve A becomes even more apparent.

The second objection has been that the life of a meter is unduly shortened by excessive wear of the moving parts while running under overload conditions, and, in particular, the pivot and jewel of the lower bearing soon show signs of deterioration.

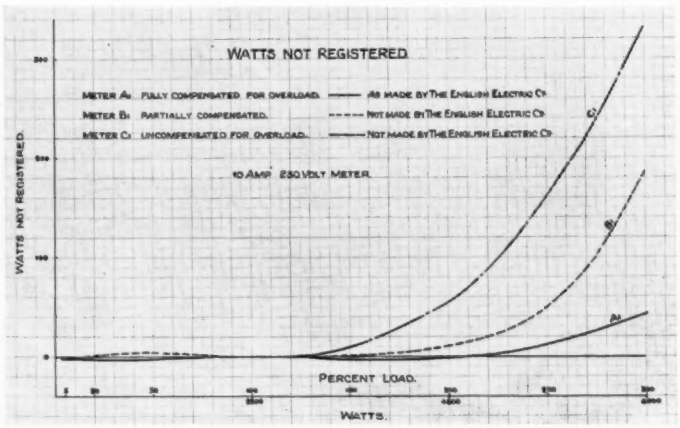

WATTS NOT REGISTERED
METER A: FULLY COMPENSATED FOR OVERLOAD. —— AS MADE BY THE ENGLISH ELECTRIC Co.
METER B: PARTIALLY COMPENSATED. ---- NOT MADE BY THE ENGLISH ELECTRIC Co.
METER C: UNCOMPENSATED FOR OVERLOAD. —— NOT MADE BY THE ENGLISH ELECTRIC Co.
10 AMP 230 VOLT METER.
WATTS NOT REGISTERED.
PERCENT LOAD.
WATTS.

Fig.1 (a). Curves for three different makes of Meter, showing watts not registered.

In this connection, there is ample experience extending over many years which proves that the Ball and double Sapphire bearing as manufactured by the English Electric Company gives exceptionally long life even when run under most severe conditions of overload. Although it is true that this bearing is far more expensive to manufacture than the pivot and single jewel bearing, the reduced maintenance costs to the Supply Company are a definite attraction.

It is appreciated that by far the greater part of the life of a house service meter is spent in metering a load which is only a fraction of its full load capacity. Notwithstanding this, it will readily be seen that the uncompensated meter entails an appreciable loss in revenue, even with overloads of short duration.

The third objection has been that many meters become noisy when running on overload. This noise emanates from such sources as loose plates in heavily fluxed cores, loose windings, adjustable lagging rings, and adjusting members. Disc-hum is also a troublesome feature.

In the design of the "English Electric" UW meter, the core of the electromagnet is of ample section to allow of a low working flux density, and the plates are rigidly riveted together. The single lagging ring of heavy section is fixed rigidly in position and is not adjustable for calibration purposes.

An important manufacturing process in the "English Electric" meter is that each electromagnet complete with its windings is baked dry, impregnated with a special baking varnish and baked again at a controlled temperature.

This process assists in the final consolidation of all parts of the unit, guarantees a completely damp proof product, and entirely eliminates the rusting of core plates.

Although the finish which this process gives may not be so attractive to the eye as coloured paper wrappings around the coils, yet a consideration of the sound reasons for the process will leave no doubt as to the wisdom of its retention.

Starting Watts.

B.S.S. No. 37 specifies starting current as 0.5 per cent. of full load. It is necessary to consider the actual value of starting watts with relation to the normal full load capacity of the meter, which it is found necessary to instal to handle a given load.

To clarify this point, assume a domestic circuit in which the connected appliances may take a total current of 26 amps. The consideration of curves in Fig. 1(a) will indicate that :—

The 10-amp. meter having characteristics as curve A is adequate for their duty, whereas a 20-amp. meter with characteristics of either curve B or C is required.

The starting current of each meter expressed as a percentage of full load would be roughly as follows :—

Meter A 0.3/0.4% of 2,300 watts = 6.9/9.2 watts.
,, B and C 0.3/0.4% of 4,600 watts = 13.8/18.4 watts.

At the lower loads the dip below 100 per cent. registration between 10 per cent and 60 per cent. in the curve of meter B is important. Both meters A and C are successful in eliminating this loss.

From these considerations it is apparent that considerable economy in capital cost of metering equipment can be effected in many instances where it is desired to instal a single meter for both lighting and power circuits.

The commercial production of meters with a consistently high standard of initial and sustained performance demands a robust design embodying sound technical principles and production facilities capable of producing all parts with great precision.

In a later issue of this Journal we shall publish a description of the modern factory which has been specially equipped for the production of a range of precision watthourmeters. A short description of the constructional and characteristic features of the Company's type UW meter now follows :—

CONSTRUCTIONAL AND CHARACTERISTIC FEATURES.

TYPE — UW SINGLE-PHASE 2½, 5, 10 AND 20 AMPERES.

ACCURACY.

The Type UW meter has an outstanding electrical performance, with a starting current of 0.3 to 0.4 per cent. of full load. The load curves for this meter are shown in Fig. 1(b), and are typical for a standard meter capable of operating on 300 per cent. of full-load continuously. This performance is attained by sound mechanical principles and precision accuracy in construction.

Fig. 2. Type UW House Service Watthourmeter.

CASE.

This is of drawn steel with channel sections to give additional strength and rigidity. An extension of similar material which is secured to the under side of the case, provides enclosure and protection for the moulded terminal-block, and at the same time completes the metal shrouding of the meter when the cover is in position. This cover is of non-magnetic material, therefore the meter can be checked or calibrated with the cover removed, thus facilitating any adjustments. The nameplate and property label are mounted

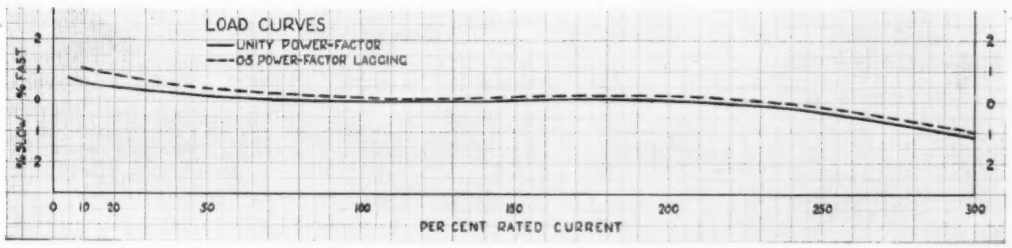


Fig. 1(b). Load Curves for the type UW Watthourmeter.

Fig. 3.

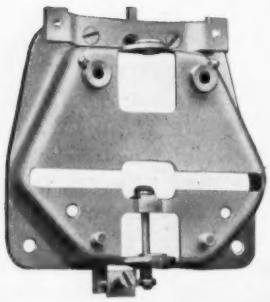


Fig. 4.

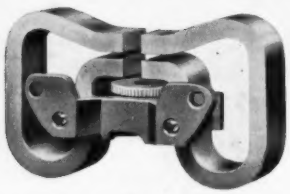


Fig. 5.

behind the window in the cover, the label being easily removed for engraving.

Frame.

The frame (Fig. 4), which is also of drawn steel, carries the complete meter element and forms a screen between the electro-magnet and the brake-magnet, thus protecting the latter if the meter should be subjected to a heavy short-circuit. The frame is mounted so that in the event of the comparatively rigid case becoming distorted due to irregularity in fixing, the transference of this distortion to the frame assembly is avoided.

Brake-Magnets.

The brake-magnets (Fig. 5) are of high-grade steel, care being taken in the processes of manufacture and ageing to ensure uniformity in all characteristics and permanency of calibration. The two magnets are permanently fixed together by means of a massive casting to form a single unit, and one magnet may be moved independently of the other, although this movement is unnecessary after the meter leaves the factory. Holes are provided in this casting to register with corresponding dowel-pins on the frames. This construction ensures that the complete brake-magnet assemble may be removed and replaced without disturbing the calibration, as the possibility of a displaced air-gap is eliminated.

Electro-Magnets.

The one-piece construction of this part is clearly seen in Fig. 7. This arrangement, by providing definite location of poles, definite flux paths, definite iron circuit, and definite pole gaps, enables a remarkably exact performance to be obtained.

Rotor.

This consists of a rigid aluminium disc, having a milled edge for stroboscopic examination, and bearing one hundred divisions on its upper face for ordinary calibration purposes. The removal of the rotor and its replacement may be undertaken without interfering with the brake-magnets by adopting the following procedure.

Removal of Rotor.—The upper bearing is first unscrewed, followed by the unscrewing and withdrawal of the lower bearing. As the latter is withdrawn, the jewel mount associated with

the main shaft is also withdrawn ; the rotor is then free and may be removed.

Replacement of Rotor.—The rotor is placed in position and the upper bearing is screwed in, care being taken to ensure that the needle enters the bearing hole in the shaft pinion, and that the bearing is screwed tight. The lower bearing is then moved upwards so that the plain end of the rotor shaft enters the split sleeve of the bearing, which must then be screwed home. Finally, the disc-hub must be pressed gently down with the fingers ; this causes the main shaft to be fully in engagement with the split sleeve of the lower bearing, and brings the disc into the correct position relative to the brake-magnet and electro-magnet. As the rotor bearings are fixed during manufacture, no adjustments are necessary and no provision is made for them ; consequently, as mentioned above, it is important that the bearings are screwed home.

Bearings.

The main or lower bearing, is " pivotless " and is of special interest. This bearing is shown in detail in Figs. 8 and 10, from which it will be noted that the bearing comprises a small, polished and hardened, steel ball running between two natural sapphires of high quality and finish.

The rolling action imparted to the ball by the revolution of the rotor shaft reduces friction to a minimum ; and as this provides in effect, a bearing with an infinite number of pivot points, wear is negligible and no lubrication is required. The advantage of this type of bearing lies in the reduced friction—which remains constant over a considerable number of years of operation —compared with single pivot bearing. This feature ensures that the starting watts and the light-load running of the meter remain unchanged.

The upper bearing is of the plain polished-steel type and acts as little more than a guide. A special grease is retained in a recess in the pinion and rotor shaft, sufficient to lubricate the bearing for a long period.

Register.

The registering mechanism, which is of sturdy construction, is a separate unit assembly, Fig. 9. The correct depth of meshing between the register and the shaft pinion is definitely fixed by locating

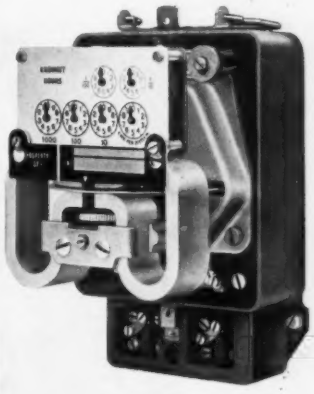


Fig. 6.

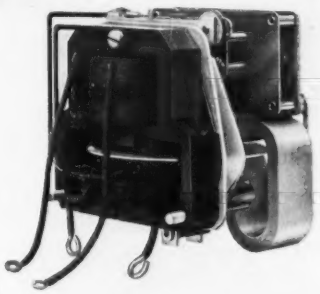


Fig. 7.

Fig. 8.

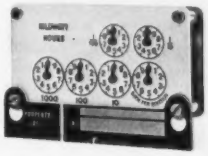


Fig. 9.

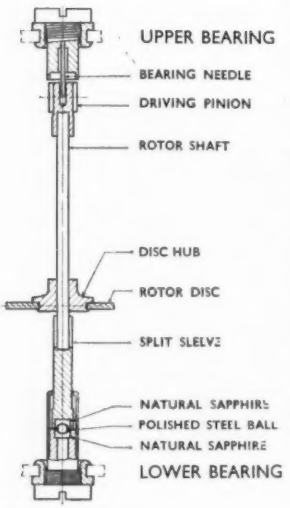


Fig. 10. Rotor Assembly.

bosses. The register is readily detachable, and is removed by slackening back two grub-screws in the locating bosses; whilst to replace the register it is only necessary to insert the locating pins in the locating bosses and screw up and lock the grub-screws.

CALIBRATION AND ADJUSTMENTS.

Three calibration adjustments are provided as follows :—

Full-load Adjuster.—This consists of a magnetic divert below the limbs of the magnets. This divert is rigidly attached to a screwed stem which fits into a tapped hole in the magnet support, and can be locked by the locking screw which is provided.

To make an adjustment the locking-screw is released, when the divert may be raised or lowered by rotation—raising the divert increases the speed of the meter, and lowering the divert decreases the speed. The edge of the divert is milled to facilitate rotation.

Light-load Adjuster.—This adjuster consists of a non-magnetic vane, which can be moved in a plane parallel to itself, and is under the influence of the shunt flux. Adjustment is effected by rotating the slotted-head screw in the direction desired, F or S; the device is self-locking.

Fig. 11. Rear View of Type UW Meter.

Inductive-load Adjuster.—This comprises a wire loop carrying an adjustable clamp. In making adjustments, the locking screw of the clamp is loosened and the clamp is moved to the right or left as required; movement of the clamp to the right slows up the meter on inductive loads, whilst movement to the left on similar loads increases the speed. When the correct position is obtained, the clamp is secured by the locking screw.

No special tools are required, as any of these adjustments may be made from the front of the

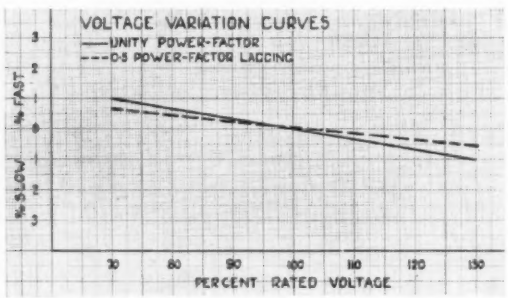


Fig. 12. Performance of Meter under Voltage Variation.

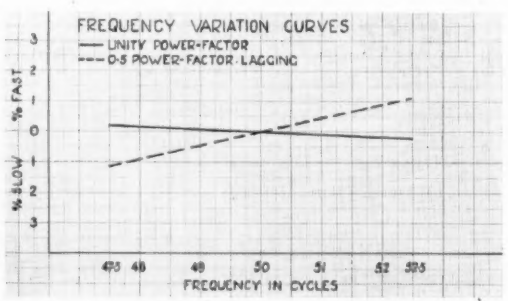


Fig. 13. Performance of Meter under Frequency Variation.

meter by means of a screw-driver held at right angles to the case.

Fixing.

The meter is fixed by two screws. The first secures the slotted link, at the back of the meter as shown in Fig. 11, to the meter board. The meter is then raised, allowing the link to slide in a specially prepared groove, thus concealing the screw; a second screw is then inserted in a hole in the meter base, passing through the terminal block into the support, and is thus protected by the cover. This arrangement prevents the meter being tampered with, or tilted to upset the registration, without breaking the seal.

Meter Settings.

All meters are accurately calibrated with precision-testing apparatus. The registration at all loads from 5 per cent. to 125 per cent. of full-load is well within the requirements of the appropriate B.S.I. specification; and the B.S.S. limits are not exceeded even on loads up to 300 per cent. full-load.

At light loads (5 per cent.) the registration is adjustable from normal to 2.5 per cent. fast, which is the B.S.S. limit. At the latter setting and with 30 per cent. excess voltage, the meter is not subject to a "voltage-creep." With the light-load vane set to give 1.5 per cent. fast registration on 5 per cent. full-load, the starting-watts are 0.3 per cent. full-load; with the light-load vane set to give normal registration at 5 per cent. full-load, starting-watts are between 0.4 per cent. and 0.5 per cent. full-load.

TECHNICAL DETAILS.

Current ratings ... $2\frac{1}{2}$, 5, 10, 20 amperes.
Voltage ... ... 220-250 volts.
Accuracy ...
Variation in voltage
Frequency and Power Factor } See curves Figs. 12 and 13.
Excess voltage ... The meter will not run on shunt with 30 per cent. excess voltage
Overload capacity. The meter is capable of withstanding the following maximum loads continuously, with the accuracy shown on the curves.

Current Rating (amps.)	$2\frac{1}{2}$	5	10	20
Maximum Load (amps.)	$7\frac{1}{2}$	15	30	30*

*Limited by terminal capacity.

Starting current ... The meter will start and run continuously on 0.3 to 0.4 per cent. of full-load.
Torque ... ... 39 gramme-millimetres.
Speed ... ... 28.75 r.p.m. at full-load.
Weight of rotor ... 17 grammes.
Type of bearing ... Pivotless. Double sapphire and ball.
Losses ... ... Shunt loss = 1.0 to 1.1 watts. Series loss = 0.4 watt. Series drop = 0.16 volt.
Temp. co-efficient ... 0.08 per cent. per degree Centigrade
Insulation test ... 2,000 volts a.c. for one minute.
Insulation resistance... Over 100 megohms.

Fig. 14. Type UWB. All-Insulated Watthourmeter.

Type UWB. Single Phase. All insulated Meter $2\frac{1}{2}$, 5, 10, 20, 40 and 50 Amperes.

With the rapid extension of rural electrification the demand for "all insulated" Meters has gradually increased, particularly for locations where the provision of earthing facilities is difficult.

The extensive experience of the Company in the design and production of bakelite mouldings places them in a favourable position for providing a well designed insulated base and cover for the Type UW Meter Element.

Accurately designed and well-moulded in suitable bakelite, the insulated meter under the symbol Type UWB is undoubtedly a very attractive instrument, and is a valuable component in any "all insulated" house service scheme.

Some idea of the strength of the moulding employed may be obtained from Fig. 15, which shows one of these meters mounted in the normal manner, with weights totalling 224 lb. placed direct on the meter cover.

As the design offers a number of features of practical interest, a brief description follows.

General Construction.

This meter comprises the well-known "English Electric" Single Phase Element Type UW (approved by the Electricity Commissioners), the design, construction and technical features remaining unchanged.

Case.

The element is housed in a handsome solid moulded base, and cover of finest quality bakelite, Fig. 14.

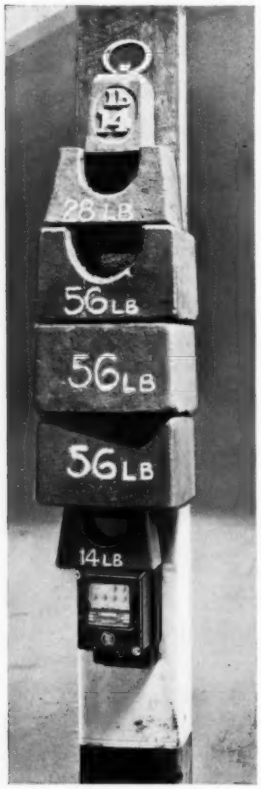


Fig. 15. Test carried out to show strength of Bakelite Case.

The base is a very rigid moulding of ample section, the terminal-block, fixing-lugs and handle-bracket, being moulded integral with the base. The element is carried in the base on a special chassis, giving two point suspension. The upper edge of the base is perfectly flat to ensure a really dust and damp proof joint between the base and the cover gasket.

The cover is a moulding of exceptional strength, and has a gasket channel to accommodate a round cord gasket of large section.

Fig. 16. Bakelite Case, showing cable entry.

The heavy gauge window is housed within a deep recess which is suitably strengthened by adequate beading moulded with the cover, the cover being reinforced by solid bakelite webs. The window is puttied in and secured by brass clips which are retained by studs and nuts. The window studs are moulded into blind holes from the inside of the cover.

The cover which is secured to the base by tension rods so located that neither the cover nor base can be accidentally broken during screwing up.

Terminal Block.

The terminal block embodies interesting and attractive features. It is moulded solid with the base to give the whole unit a degree of exceptional strength. This design also precludes the possibility of ingress of dust and moisture at the point where the terminal block and base fit together as in some designs.

The insulated cable entries (Fig. 16) into the terminal block are cone-shaped and of a depth which avoids any possibility of the live end of the cable being exposed during wiring-up. The cable socket is drilled to ample depth which ensures that the bared end of the cable is correctly gripped by both pinch-screws in each block.

These features make for ease of installation, it being unnecessary to cut the insulation back with any great degree of accuracy. Pinch screws of ample size are fitted and these are readily accessible for wiring up.

Fig. 17. Base of Bakelite Meter Type UWB.

Between each pair of inserts a wide rib of bakelite stands proud of the metal to give adequate creepage distance between live parts, and to prevent accidental short-circuit if it should be necessary to work on a live meter.

Where the terminal inserts project into the meter case, solid moulded webs standing proud of the metal give exceptionally long creepage distances.

The ends of the series windings are secured to the inner ends of the inserts by a special design of fixing screw. This arrangement facilitates connecting and disconnecting the elements from the base. Each of these screws is fitted with a captive washer to ensure perfect connection between the winding and the insert.

Shunt Disconnecting Link.

A shunt disconnecting link of special interest is fitted, see Fig. 17, and to disconnect the shunt from the series winding, screw A and screw B are loosened and the link is slid over to the right. The link then lies within a bakelite recess C and cannot accidentally fall across any live connections. The testing-voltage lead is then plugged into an additional hole D in block E, using a special plug which will be supplied if required. This arrangement ensures a considerable saving in test room time for connecting and disconnecting and also reduces the risk of accidental short-circuit between temporary wires.

Fixing.

A three-point fixing is employed. At the top of the meter is a single rugged fixing lug having an inverted keyhole-type hole. The lug is of bakelite solid with the base. Two fixing holes are provided through the bakelite terminal block. These fixing holes have a long parallel hole to support the screw during insertion. An ample recess is provided for the screw head.

Three screws are provided with each meter. One screw 1in. x 10 G for upper lug. Two screws $1\frac{1}{2}$ in. x 10 G for terminal block.

Although no special tools for fixing can be considered essential, there is no doubt that

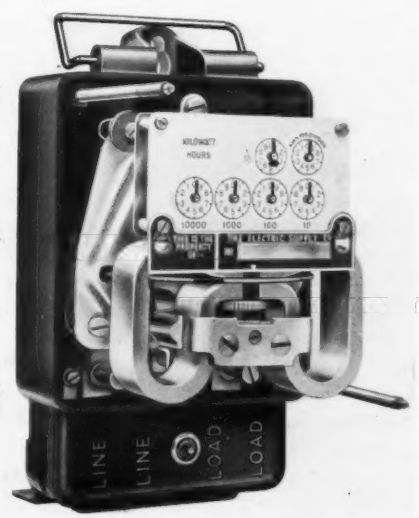


Fig. 18. Type UWB. Meter, with cover removed.

a saving in time for installation is effected by the use of a special tool for boring the mounting board. This tool is provided free with each batch of 25 meters supplied.

TERMINAL COVER.

Two types of cover are available. The standard pattern fits flush on the top of the terminal block and is used for "front of board" wiring, whilst the extended terminal cover is supplied for "back of board" wiring, its purpose being to conceal the wiring completely. Both types are slotted to permit of easy removal without the necessity of completely removing the thumb nut.

Two channels, one on each side of the terminal block, engage with strong ribs on the terminal cover to give increased rigidity.

SEALING.

Provision is made for three sealing points, two on the meter cover, and one which is independent on the terminal cover.

WEIGHTS AND SIZES. TYPE UWB.

Weight—$5\frac{1}{4}$ lbs.

Overall size with standard terminal cover—$7\frac{7}{8}'' \times 4\frac{3}{4}'' \times 5\frac{5}{16}''$ deep.

Overall size of extended terminal cover—$10\frac{1}{4}'' \times 4\frac{3}{4}'' \times 5\frac{5}{16}''$ deep.

A.C. Arc-Welding Equipments.

By T. A. LONG, A.M.I.E.E.

The field of application of electric arc welding is extending considerably and the Company have met this expansion by adding an A.C. arc welding equipment to their range of electric welding products. Large numbers of these equipments have been supplied and are giving efficient and trouble-free service amongst a wide variety of industrial users.

Considerable attention and research has been given to welding in recent years as witness the Welding Symposium held in May, 1935, under the auspices of the Iron and Steel Institute.

Prospective users of welding equipment can, with every confidence, adopt welding without further protracted individual tests and research. There is no doubt that in a great many cases, fabricated welded structures can be used instead of castings or built up riveted or bolted structures with an appreciable economy in cost and weight.

Electric arc welding with the scientifically fluxed electrodes now available is a process which on account of its efficiency, low cost, speed and all-round adaptability compares very favourably with any other method for the joining together of ferreous metals.

All grades of commercial steel may be electrically welded with the exception of tool steel and spring steel which have a very high carbon content.

It is also possible to weld stainless steel although this requires careful control of the welding current and it is essential to have the correct electrode to suit the particular grade of parent metal. Stainless steel is a poor conductor of electricity and for this reason it is necessary to use only a short length of the electrode, say 3 inches, and then to change the electrode and allow the first one to cool down. If this precaution is not taken the electrode is liable to become red hot and further welding becomes impossible.

Compared with the oxy-acetylene or the gas method of welding the electric-arc method has many advantages. In gas welding a high temperature flame is produced by the ignition of a mixture of two gases, usually oxygen and acetylene. It is necessary correctly to proportion the gas and to maintain the correct gas pressure, and these are controlled by devices on the torch.

The welding process consists first of pre-heating the metal to be welded with the torch flame and when this is molten the weld metal is added with a filler rod. It is necessary constantly to play the flame over the molten pool of metal with the result that a wide area of metal around the point of welding reaches a high temperature, for this reason thermal stresses and distortion effects are very bad and the oxy-acetylene method cannot be recommended for high quality welding.

Even where the quality of weld deposit is not of paramount importance it is found that in spite of the comparatively low initial cost of the

equipment the operating costs are so high as to make the method uneconomical. The overall working costs of the electric-arc process are considerably lower than with gas welding ; the speed of welding is higher and as the heat is definitely localised distortion effects are not evident to the same extent.

The chief application for an oxy-gas or oxy-acetylene torch equipment is for cutting ; and used for this purpose it is a very valuable adjunct to an arc welding plant as unusual metal shapes may be accurately cut out prior to assembly and welding by the electric-arc process.

This description of the electric-arc process is confined to the more generally used process of metallic arc welding. In principle this process consists of striking and maintaining an electric arc between the work to be welded and a metal rod or electrode gripped in a suitable holder.

A higher voltage is required to initiate or strike the arc than is required to maintain it. As soon as the arc is struck a very high temperature (approximately 6,500 deg. F.) is created at the point of welding. Under the intense heat developed a small part of the work to be welded and the tip of the electrode is brought to a molten state. The molten parent metal is agitated by the action of the arc and tiny globules of molten electrode metal are impelled across the arc stream and intimately coalesce forming a homogeneous whole. It should be appreciated that the globules are impelled along the arc stream electrically and do not fall simply by the force of gravity.

This explains why it is possible to weld satisfactorily in an overhead or vertical position. It is, of course, easier to weld in the downward position where gravity assists the arc stream, and this position should be chosen wherever possible.

It is well known that molten metal very readily takes up oxygen and nitrogen. If exposed to the atmosphere, molten steel enters into chemical combination with the atmospheric oxygen and nitrogen to form oxides and nitrides which become entrapped in the steel. These impurities tend to change the physical properties of the steel and to weaken and embrittle it as well as to lessen its resistance to corrosion. These difficulties were recognised early in the development of electric arc welding and much time and research has been spent to produce an electrode which would overcome these draw-backs.

There are various types of electrodes on the market which are covered with a flux, the object of which is to protect the arc stream and to act as a reducing agent. The advent of the shielded-arc electrode is the latest advance in this direction and this has still further improved the quality of welding and eliminated to a large extent the need for the preparation of the joints by veeing or other means.

The object of the shielded-arc electrode is to protect the arc stream and small pool of molten metal by a shielding envelope of gas such as hydrogen. Hydrogen is a very active reducing agent and if the gas shield can completely protect the arc the injurious chemical combination with the gases in the atmosphere cannot take place. This is accomplished without the deposition of a heavy layer of slag, and with a good quality shielded-arc electrode the slag can be easily brushed off with a wire brush, no chipping being necessary.

The successful use of shielded-arc electrodes has led to the adoption of heavier gauge electrodes using higher currents. There is no doubt that the trend of welding at the present time is towards the use of fewer runs of heavy gauge electrodes instead of using small electrodes and multiple runs. This point has been exhaustively investigated by a number of independent research engineers. The result of these tests show almost complete unanimity that there are no deleterious effects in using the heaviest possible gauge of electrode and that, in fact, the test results are better.

Shielded-arc electrodes are characterised by a high arc voltage drop and by the fact that the flux covering burns at a slower rate than the metal core. The application of shielded-arc electrodes has made evident the advantages of A.C. arc welding.

It is well known that either alternating or direct current can be satisfactorily used for welding. The English Electric Company manufacture both types of equipment, and these are regularly in use in their welding and fabricating shops.

In the past there has been divergence of opinion as to the relative merits of the two processes. A number of harmful and entirely fallacious views have been held regarding the A.C. process, but these are rapidly changing as experience of recent

A.C. welding equipments is proving its suitability for wide applications.

Apart from the ease with which it is possible to transform an alternating current supply to the correct current and voltage, the application of alternating current for welding has a number of other noteworthy advantages.

With the use of heavy gauge electrodes and the consequent high welding currents the magnetic blow effect associated with the D.C. process makes it difficult to deposit good quality weld metal in awkward places such as inside tanks, corners and joints requiring overhead welding, whereas the A.C. process entirely eliminates this disadvantage and has led to its general adoption for heavy current welding.

In America, where D.C. welding has been held high in favour, it has become recognised that the A.C. process holds many advantages and A.C. welding equipments have been developed there for 500, 750 and 1,000 amp. units per operator.

The progress in high current heavy gauge welding has not been quite so rapid in this country, but equipments for the supply of 400 amps. per operator are now becoming quite frequent.

A.C. welding equipment is considerably cheaper in initial cost compared with a D.C. equipment of an equivalent output, and has also an appreciably higher operating efficiency. As a rough guide the approximate ratio between initial cost of A.C. and D.C. equipments is 0.55/1 and the ratio of their efficiencies 1/0.7.

One of the chief criticisms levelled against the general process of welding has been the reliance that it is necessary to place upon the skill of the welding operator. Although test samples can be made and tested in the laboratory such samples are not necessarily an accurate guide to the quality of welding actually being consistently carried out on a production job. It is acknowledged that a good class welded joint is the cheapest and most efficient method of joining two pieces of ferreous metals and such joints can be made stronger than the parent metal.

Any process of welding, therefore, which tends to minimise the possible errors of the operator is to be recommended, and it can be fairly claimed that consistently good quality welding can be attained with the A.C. process.

This claim is based on the fact that with the A.C. process a long-drawn-out arc is not possible. It is essential in welding that a short arc be maintained in order to secure an efficient energy transfer and good penetration of the deposited weld metal into the parent metal. With a drawn-out arc a good quality weld deposit would not be possible. The weld metal would simply be " puddled in " with very little penetration.

The advantage gained, therefore, is that the A.C. arc constrains the operator to keep the arc consistently short during welding. It might be thought as a parallel to this that the A.C. arc is hard to hold, but that is not the case, the operator finding in practice that it is as easy to maintain an A.C. arc as it is a D.C. arc.

So far only the advantages of A.C. welding with reference to the welding process itself have been mentioned. The electrical advantages are well known and need not be stressed. The advantage of having a welding equipment without moving parts or intermediary converting losses is self-evident.

In respect of the power factor of welding loads a careful comparison between the usual types of A.C. and D.C. plant shows that a low operating power factor is common to both types and any advantage lies slightly with the A.C. equipment. With the Company's type of equipment the operating power factor is of the order of 0.5 on

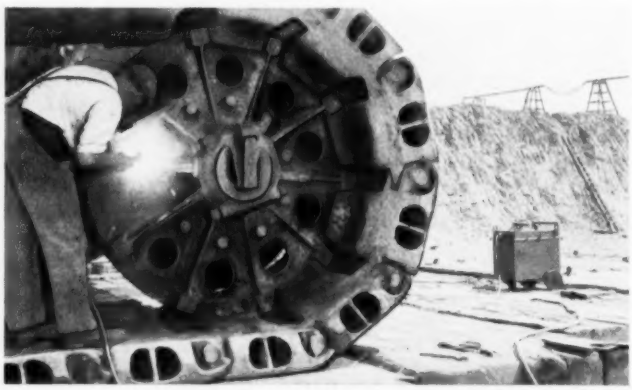


Fig. 1. Carrying out a Repair to a Mechanical Navvy by means of A. C. Arc Welding ; the Portable Equipment is seen on the right.

an average multi-operator equipment. This is not so serious as it might at first appear as the welding load of the average industrial undertaking is only a very small proportion of the total load. The reduction of power factor is not usually sufficient to affect any tariff rebate allowed by the Supply Company for good power factor. It is, of course, always possible to correct the low power factor by means of static condensers but their installation is not recommended except in the case of large installations. It must also be remembered that the ratio of connected time to welding time is in the average welding shop of the order of 40 per cent. That is to say, when allowance is made for changing of electrodes, de-slagging, etc., the time actually spent on welding would be 40 per cent. of the time the plant was connected to the supply system. During the remaining 60 per cent. of the connected time the plant is only drawing sufficient electrical energy from the supply system to feed the " no load " losses.

It may be opportune at this stage to point out that for the welding of certain non-ferreous metals, such as copper, that D.C. is essential. D.C. welding is also generally acknowledged to be superior for bare wire welding. The question of whether bare wire welding is in any circumstances more economical or satisfactory for even certain applications is a controversial point. It is certain, however, that where a good quality weld deposit is required having ductility, a good grade flux covered electrode is essential. The ultimate tensile strength value of a bare wire weld is approximately half that of a weld made with a good quality fluxed electrode.

Another defect, in bare wire welding is the low Izod impact values obtained in the joints which means that the resistance to shock loads is low and a bare wire weld should only be used where the load on the joint is quite static.

The English Electric Company's A.C. arc welding equipment consists essentially of a transformer unit feeding one or more welding regulators. The transformer may be either of the indoor or outdoor type and is fitted with primary tappings at 380, 400, 420 and 440 volts to make it suitable for use on any supply system within this range of voltage.

The primary tappings may also be used as secondary voltage adjusting tappings, if necessary, to compensate for any excessive voltage drop in the inter-connecting cables.

The normal secondary pressure of the supply transformer is 90 volts and this is the voltage available to the operator for striking the arc. The secondary pressure of 90 volts was chosen after very careful investigation and is based on a wide experience of welding for all classes of application. It is also generally acknowledged by welding engineers that this voltage is necessary for satisfactory welding with shielded arc electrodes having high arc voltage drop characteristics.

The Home Office Regulations fix an upper limit of 120 volts for A.C. welding equipments and the secondary pressure of 90 volts easily conforms, therefore, to these requirements.

Every care has been taken in the design of the equipment to safeguard the operator and to render the equipment safe and fool-proof so that no unauthorised person is able to gain access to any line or vulnerable part of the equipment.

The welding regulator serves as a means for each individual operator to control the welding current to a value suitable for the particular type and size of electrode being used. The appropriate current value is controlled by means of tappings connected to an externally operated

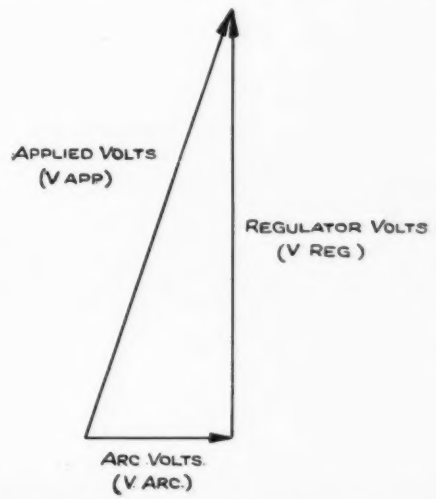


Fig. 2. Vector Relations of Arc and Regulator Voltages.

tapping switch, which is fitted with a notched plate graduated in welding amperes.

The welding amperes marked on the switch plate are substantially correct, independent of the type of electrode being used, as may be seen by a consideration of the electrical conditions of the circuit.

It is well known that the arc voltage drop varies with the type of electrode ; the bare wire electrode having an arc voltage drop of approximately 18 volts whereas the heavy shielded arc electrode may have a voltage drop of the order of 35 volts. The arc voltage is practically in phase with the welding current and the regulator voltage in quadrature as shown in Fig. 2. The applied voltage from the supply transformer is constant at 90 volts and any change in the welding current is proportional to the change in the regulator voltage.

$$\text{NOW } V \text{ Reg.} = \sqrt{\text{Vapp}^2 - \text{V arc}^2}$$

Let us now assume that the regulator is set by means of the tapping switch to give an output of 200 amps. (to suit a 4-gauge electrode) and that the arc voltage drop is 25 volts for the particular type of electrode being used. Substituting in the formula to give regulator volts we have :—

$$V \text{ Reg.} = \sqrt{(90)^2 - 25^2} = 86.8 \text{ volts.}$$

If an electrode of the same size but having an arc voltage drop of 35 volts is used it is found that the reactor voltage will be 83.3 volts. It will be appreciated that a 40 per cent. variation in the arc voltage is very large, but even so, this variation only results in a 2 per cent. change in the regulator voltage, and, in consequence, only the same small change would take place in the welding current, i.e., from 200 to 196 amps.

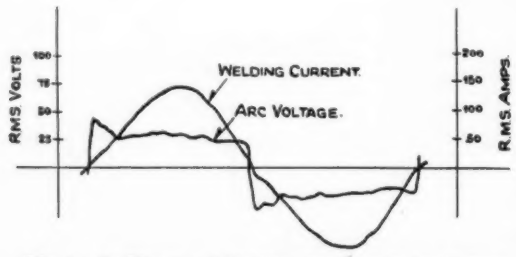


Fig. 3. Oscillogram of Welding Current and Arc Voltage.

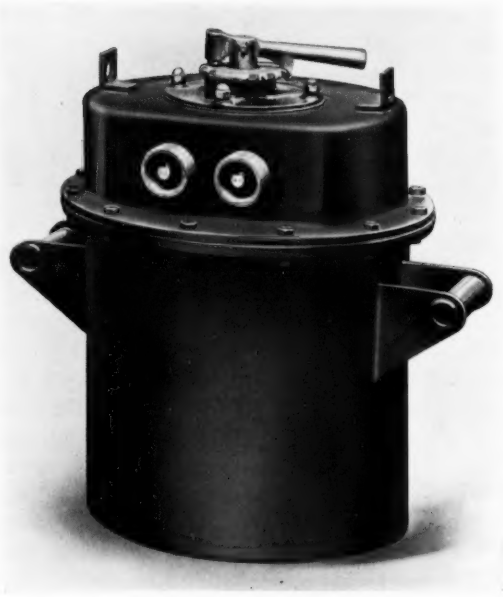


Fig. 4. 250 ampere output Welding Regulator.

This important relationship between the arc voltage and the regulator voltage is of great value, as it renders unnecessary the use of separate ammeters for the measurement of the welding current, and also serves to give the welding regulator an automatic self-regulating characteristic independent of the type of electrode being used.

The welding regulator is also designed to serve one other important function, viz., to maintain the welding current as near sinusoidal as possible. Fig. 3 shows a copy of an actual oscillogram of the welding current and arc voltage. The oscillogram shows clearly how closely the welding current conforms to the ideal sine-wave shape and that " dead " periods when no power is given to the arc are entirely absent. The value of this condition is to ensure that the welding arc is stable, free from spluttering and that a good sound homogeneous weld free from porosity is deposited, and photo-micrographs of the weld deposit prove

this to be the case. Fig. 4 shows a 250 ampere output welding regulator.

The regulator is of robust construction and weatherproof for outdoor service without any further protection. Special care has been taken in the design of the unit to make it suitable for the rough usage likely to be met with in shipyards and fabricating shops. The regulator shown would in most cases form one unit of a multi-operator set. A multi-operator welding equipment consists of a specially designed transformer supply unit for supplying electrical energy to a number of separate welding regulators.

It is desirable to limit the number of regulators being supplied by each transformer to a maximum of twelve. This recommendation is made so that it will not be necessary to provide cables for an uneconomic heavy low-tension current which would have high stray losses and excessive voltage drop.

In the layout of the electrical equipment for a welding shop in which A.C. arc welding plant is used certain precautions are necessary to ensure satisfactory operation. One of the more important of these, especially with heavy current welding, is the avoidance of excessive voltage drop along the length of interconnecting cables. This voltage drop would manifest itself as a reduced voltage at the regulator terminals and, if excessive, would tend to interfere with the welding process.

As an indication of the voltage drop that may be expected due to the impedance (reactance and resistance) of the interconnecting cables the following conditions will be assumed and a typical case calculated. Each phase should be considered separately and the calculation repeated for the other two phases. It is assumed that a 6-operator transformer as shown in Fig. 5 is feeding six 250-ampere welding regulators. In order to estimate the worst possible voltage drop it is also assumed that the two welding regulators on the phase under consideration are each being operated at their maximum output of 250 welding amperes.

The phase to neutral voltage is nominally 90 volts but this is compensated for in the design, for the average voltage drop; and the open-circuit voltage at the transformer terminals is actually 95 volts. It will be seen that the current flowing from the transformer along the distance D to the first regulator point is 500 amps., i.e. the sum of the two welding currents. The current from the first to the second regulator is 250 amps., i.e. the distance D_1.

Theoretically, the cable size between the first and second regulators could be reduced in section on account of the lower current. In practice very little, if any, saving would be effected by taking advantage of this reduction in current owing to the relatively short length of cable entailed. The distance between conductor centres is assumed to be 3 in. and from a consideration of the formula it will be seen that the two cables should be kept as close as possible for the minimum voltage drop.

The impedance drop in the cables consists of the sum of the reactance voltage drop and the resistance voltage drop in quadrature, i.e., added at vector right angles.

Now % Reactance =

$$\frac{8.81 \times I \times D}{E \times 10^3} \times \log \frac{1.28 \times d}{r} \text{ at 50 cycles.}$$

where I = amperes.

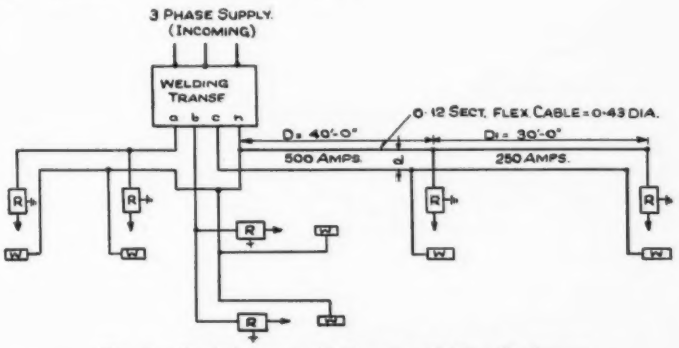


Fig. 5. Typical layout of 6-Operator Welding Equipment.

E=Applied volts (open circuit).

D=Distance transformer to welder in feet.

d=Distance centre to centre of cables in inches.

r=radius of copper cable in inches.

Considering firstly the reactance from the transformer to the first regulator and substituting we have :—

$$\% \text{ Reactance} = \frac{8.81 \times 500 \times 40}{95 \times 10^3} \times \log \frac{1.28 \times 3}{.215}$$

$$= 1.86 \times \log 17.8 = 2.32\%$$

Reactance drop $= 95 \times 0.0232 = 2.2$ volts.

$$\text{Resistance (ohms)} = \frac{0.84 \times \text{Length in feet} \times 10^{-5}}{\text{Section (sq. ins.)}}.$$

$$\text{Substituting} = \frac{0.84 \times 40 \times 10^{-5}}{0.12} = 0.0028 \text{ ohms.}$$

Resistance drop $= 500 \times 0.0028 = 1.4$ volts.

Total Impedance voltage drop in cable $=$

$$\sqrt{2.2^2 + 1.4^2} = 2.61 \text{ volts.}$$

This is the total voltage drop in the cables up to the first welding regulator. The calculation can now be repeated for the 30 ft. length of cable carrying 250 amps. between the first and second regulator, which gives an impedance voltage drop in that length of cable of 0.98 volts. To this must be added the voltage drop to the first regulator giving a total voltage drop at the terminals of the second regulator of 3.6 volts.

It is interesting to note that if the spacing between the cables had been 36 in. instead of 3 in. as assumed in the calculation, the voltage drop at the first and second regulator would have been increased to 4.36 volts and 6.1 volts respectively. These calculations assume that there is no magnetic material in close proximity to the current carrying cables as this should be avoided as far as possible otherwise the voltage drop will be materially increased.

It is evident that where the welding regulators are situated at distances remote from the supply transformer this question of voltage drop may assume serious proportions unless precautions are taken to minimise it.

In a multi-operator set it is very necessary that each welding operator should be able to work quite independently without electrical interference from adjacent operators being supplied by the same transformer supply unit. An instance of this interference may take the form of, say, one welding operator using a No. 12 gauge electrode finding it difficult to maintain a stable arc, if one or more adjacent operators were using, say, No. 4 gauge electrodes. It is possible to achieve this freedom from interference by the use of special

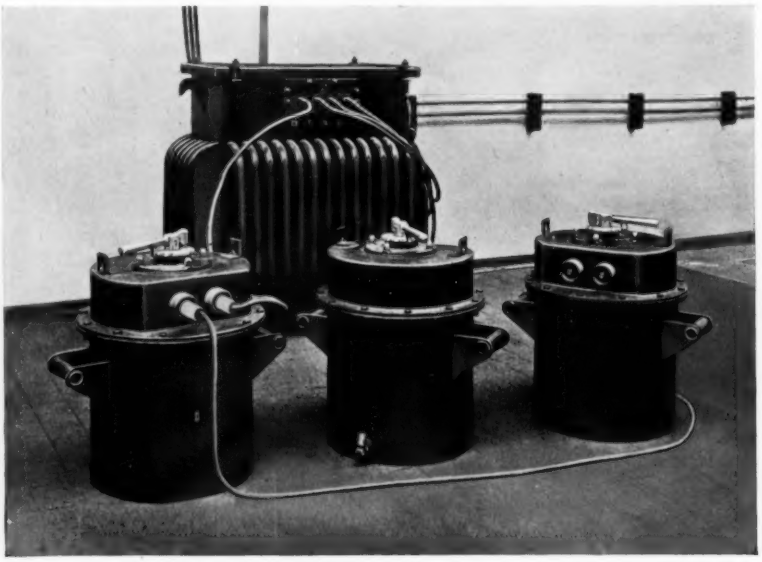


Fig. 6. Multi-Operator Welding Transformer with three of the six Regulators being supplied.

internal connections and by liberal design and rating of the active material in the transformer.

Fig. 6 shows a multi-operator transformer with three of the six regulators being supplied.

Fig. 7 shows a typical diagram of connections for a multi-operator set and also shows the current distribution if only one phase is loaded. This condition is the worst possible condition of electrical unbalance that can arise and would only occur in the event of all the welders at work being connected to the same phase of the supply transformer. The assumed condition is extreme and in practice unlikely ever to occur, but even so it clearly demonstrates how the current would be distributed between the phases and in the interconnecting cables. In normal operation with the full complement of operators at work a balanced symmetrical loading of the supply system would result.

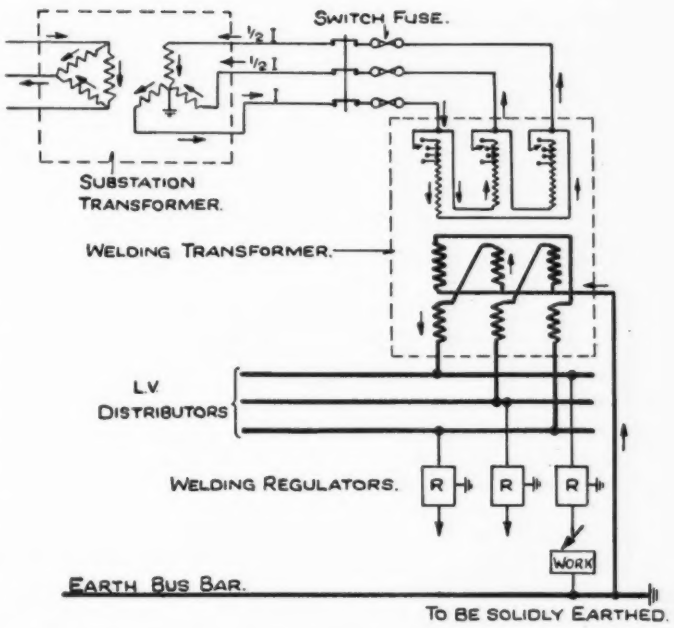


Fig. 7. Diagram of Connections for Multi-Operator A.C. Welding Equipment showing Current Distribution with only one phase loaded.

Where a number of welding operators are required to work in fairly close proximity to each other, such as in shipyard welding or in an engineering fabricating shop, the multi-operator equipment is strongly to be recommended. The initial cost per operator is minimised and the overall efficiency and running costs are appreciably better than if a number of single operator equipments were installed. In cases where for the present only a relatively small amount of welding is carried out but where it is anticipated that this will be increased, it is advised that a transformer unit large enough to meet the anticipated load be purchased but only sufficient welding regulators to meet the immediate requirements.

This form of purchase will allow the addition of further welding operators at the least possible cost. The listed range of English Electric equipments (Publication R.63) shows how flexible is the method of application.

Fig. 8 shows a portable type single operator welding equipment. The application of this type of unit is usually in either small welding shops or for use in a large erection or repair shop where it is not convenient to move the work to be welded. For both these applications it is desirable to have the transformer and welding regulator combined in a single tank, mounted on wheels for ease of portability.

The complete welding equipment can then be moved to the actual work in hand and the welding carried out with the minimum of movement. The unit shown on the left in the illustration is fitted with a fuse switch for the control of the electrical supply to the equipment, alternatively this could be fitted at the plug point if desired.

Protected and mechanically interlocked, plug and socket connectors are provided for direct

connection by a flexible cable to the supply mains. The unit is mounted on wheels; the leading wheel being of the ball bearing castor type enabling it to be moved about in confined spaces.

The supply transformer of a single operator A.C. Welding Equipment may be of two types.

(1) A two-wire single-phase transformer.

(2) The reversed vee/open delta 3/1 phase transformer.

It is sometimes claimed for the 3/1 phase transformer that it converts the 3-ph. supply current to the single-phase current necessary for welding. This claim is not true in fact, as it is impossible to convert single-phase current into three-phase, or vice versa, with any form of static apparatus. The 3/1 phase transformer serves only to redistribute the single-phase current into the three phases of the supply.

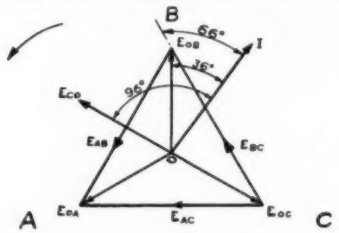
The current in the primary of the transformer remains, however, single-phase in character and returns as such to the supply mains. Figs. 9 and 10 show an analysis of the conditions with the two types of transformer. It will be seen that the 3/1 phase form of connection effects a slight gain in the current distribution but this is more than off-set by the disadvantages that result.

The comparison between the two types of transformer may be summarised :—

(1) Ratio of current loading in supply mains and substation transformer is :— Single-phase welding transformer 1 : 1. 3/1 phase welding transformer 1/2 : 1 : 1/2. As the limit of the loading of the supply mains is the limit of the loading of any one of the supply lines no advantage is gained by the 3/1 phase transformer.

(2) Owing to the low internal power-factor of the 3/1 phase type of connection 15 per cent. more kVA. of plant is required to be installed by the supply company and the consumer, for the supply of a given single-phase load through a 3/1 phase transformer.

SINGLE PHASE LOADING ACROSS 2 LINES OF A 3 PHASE SUPPLY SYSTEM. 0·4 POWER FACTOR LAGGING LOAD.



Phase Pressures of Supply = EOA; EOB; EOC; = EO.
Line Pressures = √3 x Phase Pressures = EAC; EBC; EAB.
Load Current I at P.F. 0·4 Lags 66° behind EBC, as Load is connected across lines B C.
Load Current I Lags Phase Pressure, EOB 36° = Cos 0·81.
Load Current I Lags Phase Pressure, EOC 96° = -Cos 0·105.

SUPPLY LINE AND TRANSFORMER UNBALANCING. SINGLE PHASE LOAD ACROSS LINES OF A 3 PHASE SUPPLY 0·4 POWER FACTOR LOAD.						
PHASE A.	PHASE B. P.F. = 0·81 LAG.			PHASE C. P.F. = 0·105 LEAD.		
	TOTAL AMPS	POWER AMPS	REACTIVE AMPS	TOTAL AMPS	POWER AMPS	REACTIVE AMPS
NIL.	100%	81%	58·8%	100%	10·5%	99·5%

Fig. 9.

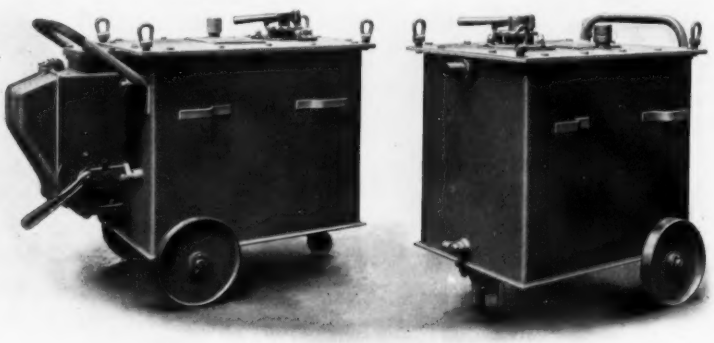
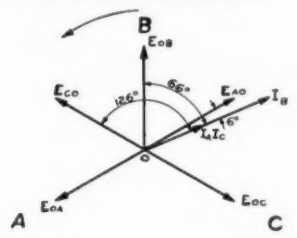


Fig. 8. Portable type Single-Operator Arc Welding Equipment.

SINGLE PHASE LOADING OF A 3 PHASE SYSTEM BY USE OF OPEN DELTA/REVERSED VEE (3/1 PHASE) TRANSFORMER

0·4 POWER FACTOR LOAD



Phase Pressures of Supply = Eob, Eoc = Eco, Eoa = Eao
Load Current Ib = 100%, Ia = 50%, Ic = 50%
Ib lags behind Eob 66° = 0·4 P.F. lag.
Ia lags behind Eoa 6° = 0·99 P.F. lag.
Ic lags behind Eoc 126° = −0·588 P.F. lag = 0·588 P.F. lead.

SUPPY LINE AND TRANSFORMER UNBALANCING								
SINGLE PHASE LOAD THROUGH 3/1 PHASE TRANSFORMER								
0·4 POWER FACTOR LOAD								
PHASE A. P.F. = 0·99 LAG.			PHASE B. P.F. = 0·4 LAG.			PHASE C. P.F. = 0·588 LEAD.		
TOTAL AMPS.	POWER AMPS.	REACTIVE AMPS.	TOTAL AMPS.	POWER AMPS.	REACTIVE AMPS.	TOTAL AMPS.	POWER AMPS.	REACTIVE AMPS.
50%	49·5%	5·2%	100%	40%	91%	50%	29·5%	40·5%

Fig. 10.

(3) The increase in transformer losses, due to the increase of installed kVA. of plant, as explained under (2), is of the order of 22 per cent.

(4) The 3/1 phase transformer costs approximately 17 per cent. more than a single-phase tranformer of equivalent kVA. output.

(5) If it is desired to correct for the low power factor load, this is quite a simple application with the aid of static condensers in the case of a single-phase transformer, but becomes a considerably involved application for a 3/1 phase transformer.

(6) The loading of a 3/1 phase transformer across the supply mains cannot be balanced by the addition of other single-phase loads without the running of an additional fourth wire to the neutral of the substation transformer. This is not always convenient and is not necessary in the case of the straight single-phase transformer connection.

The question of single or 3/1 phase transformers has been dealt with at some length as it has been found that some supply engineers insist on the installation of 3/1 phase transformers and are evidently under a wrong impression as to the relative merits of the two types of transformer.

As a general guide to prospective users of welding equipment the following table may be of service.

Electrode Gauge	14	12	10	8	6	4
Welding Current	40	65	105	135	165	190
Time, minutes, per foot of weld ...	1	1½	2	3	3	3½
Arc Volts ...	22	22	25	27	30	32
K.W.H. (units) ft.	0.013	0.032	0.078	0.16	0.22	0.31

The above table is only an approximate guide as so much depends upon the welding operator, the

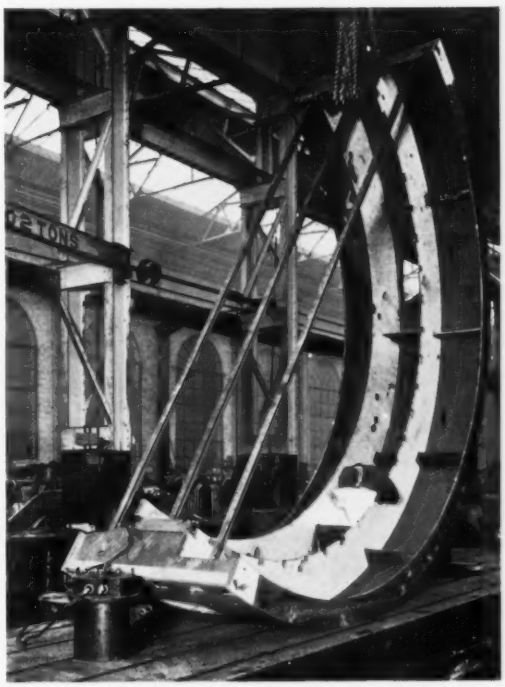


Fig. 11. Large Stator Frame of 13,125 kVA. Alternator in process of fabrication.

preparation of the joint and its accessibility, but the figures given are average for a plain butt weld joint and the times given allow for de-slagging and changing of electrodes. It will be appreciated that only a rough guide is possible as the optimum welding currents depend upon a number of factors, e.g., type of electrode, type of joint, i.e., whether butt, fillet or lap ; and also whether there is a large volume of metal adjacent to the weld which has a high thermal capacity and acts as a cooling medium to the electric arc.

An experienced operator will soon know from the characteristic sound of the arc and the way the metal is running whether more or less current is required.

To an experienced inspector a visual examination of the weld can be a very good guide as to whether correct welding practice is being followed. The variable factors over which the operator has control are the correct amount of current, the right length of the arc, and the correct speed of travel. The four chief points to be noted are the burn of the electrode, the penetration or fusion (note the crater), the sound of the arc, and the appearance of the weld deposit.

Fig. 11 shows a large stator frame of a 13,125 kVA., 250 R.P.M. alternator in process of fabrication. Some of the great advantages and flexibility of the welded type of construction can be appreciated from this example.

The application of welding to fabricated structures started five or six years ago and has developed very rapidly during the past 12 months, but there is no doubt that many manufacturers of ferreous products could apply welding a great deal more extensively with appreciable saving in their production costs.

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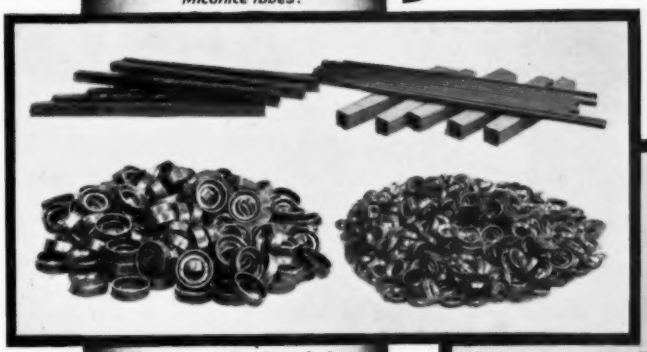

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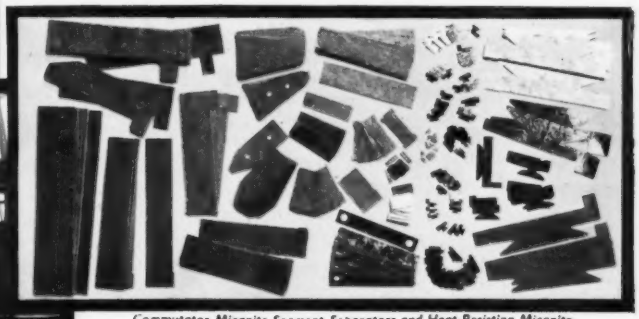

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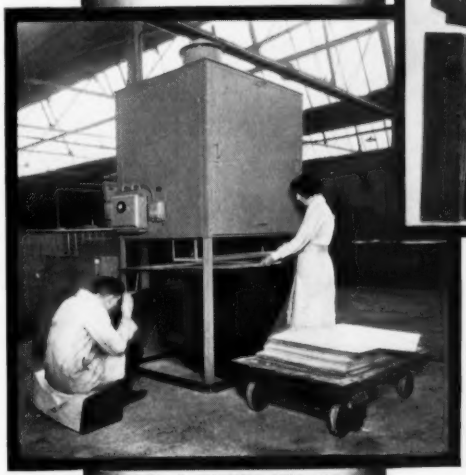

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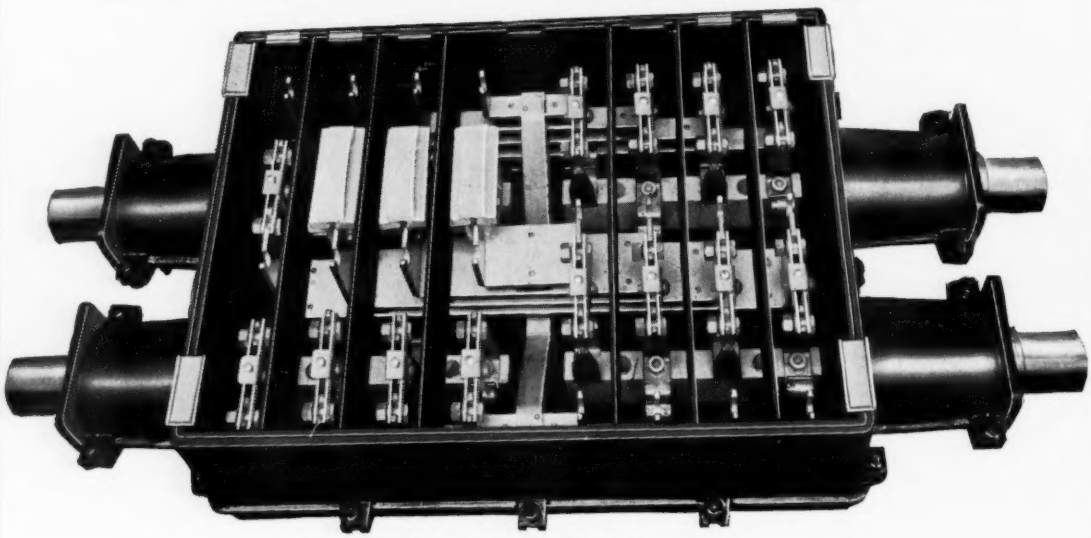

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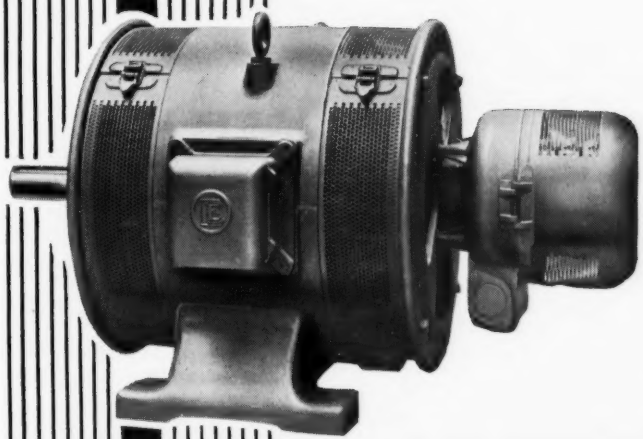

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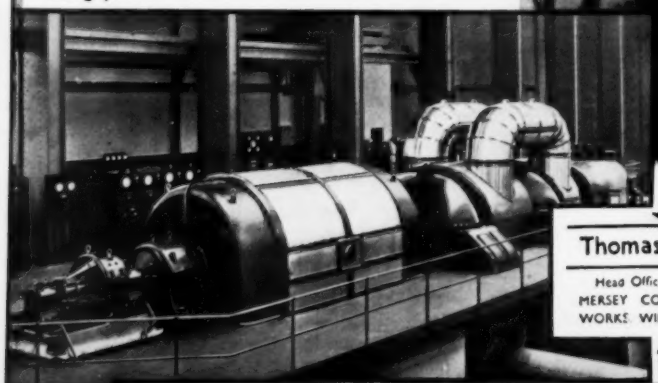

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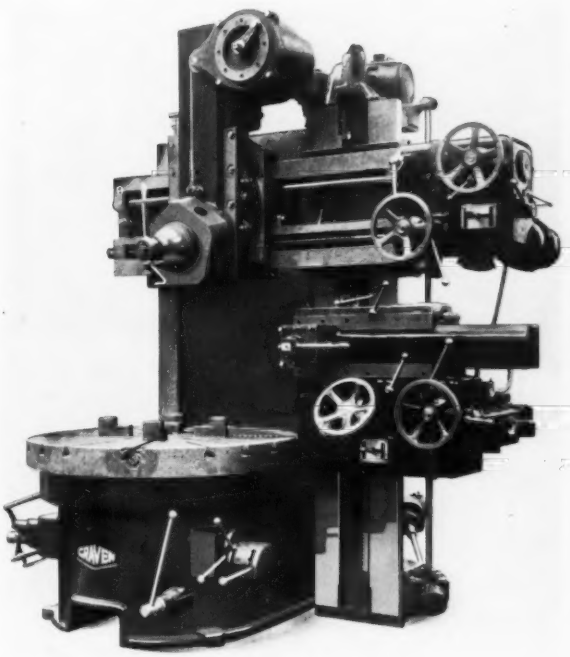

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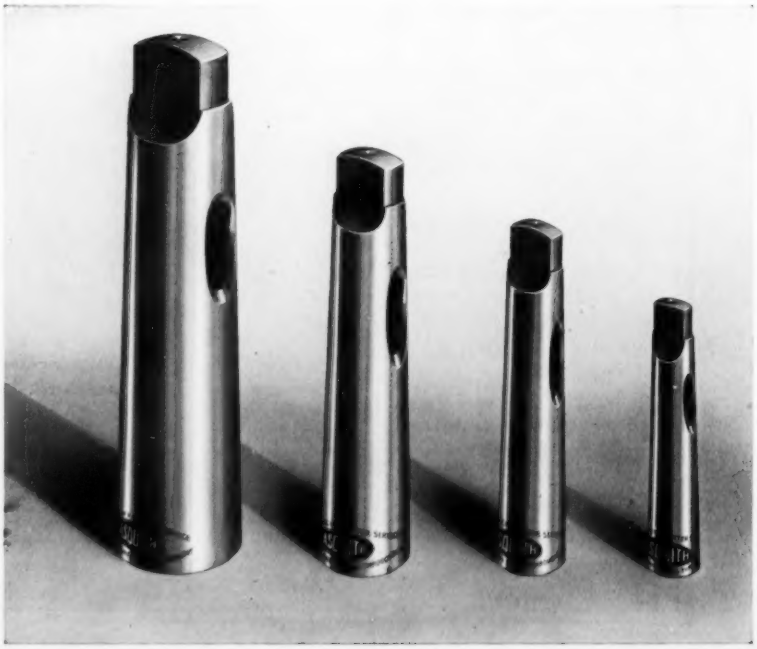

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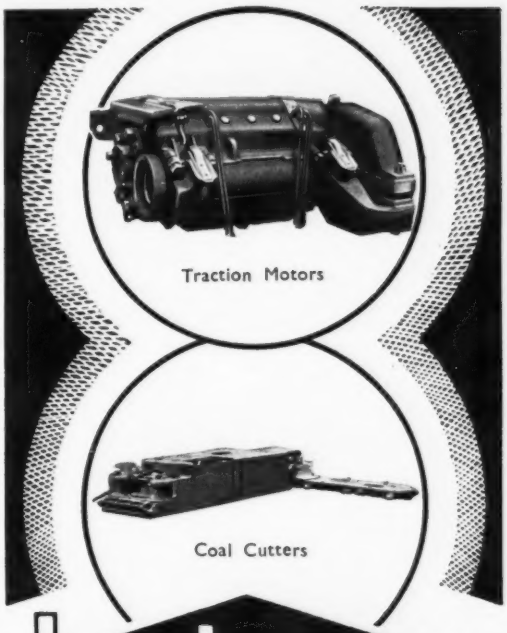

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